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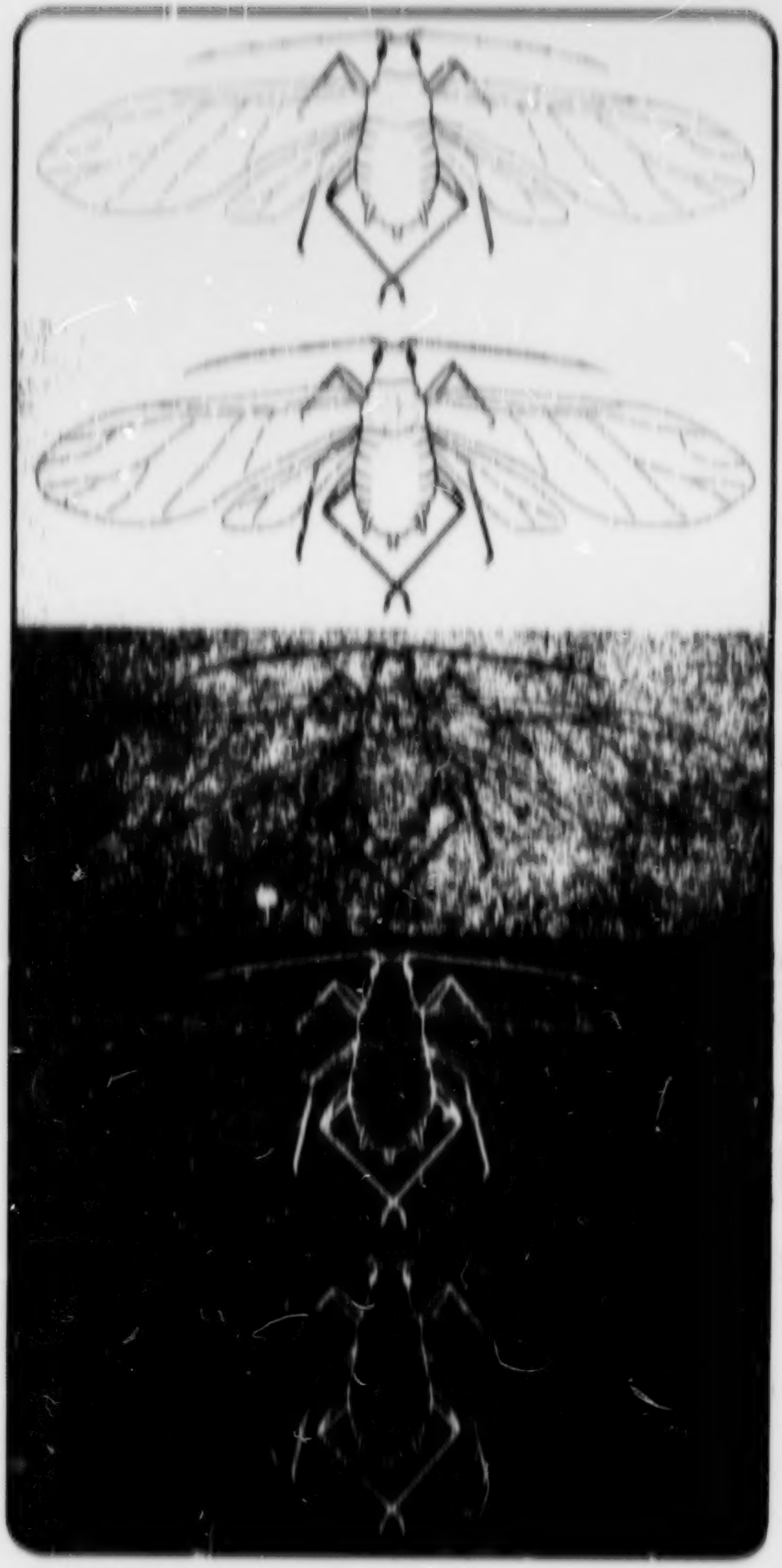

Proceedings,
U.S.-U.S.S.R.
Symposium:

The Integrated Control of the Arthropod, Disease and Weed Pests of Cotton, Grain Sorghum and Deciduous Fruit

September 28 - October 1, 1975
Hilton Inn, Lubbock, Texas

The Texas Agricultural Experiment Station, J. E. Miller, Director,
College Station, Texas; The Texas A&M University System
in cooperation with

Agricultural Research Service, U.S. Department of Agriculture
Cooperative States Research Service, U.S. Department of Agriculture
U.S. Environmental Protection Agency

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The Texas Agricultural Experiment Station
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U.S. Environmental Protection Agency

Participants of the U.S./U.S.S.R. Pest Management Conference on the Integrated Control of the Insect Pests of Cotton, Sorghum and Deciduous Fruit, Lubbock, Texas, September 28–October 1, 1975.

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Integrated Pest Management

A Foreword to the Conference

P. L. Adkisson
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Professor and Head, Entomology Department
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The protection of crop plants from arthropod, disease and weed pests is one of the most important components of a profitable farming system. During the evolution of man and agriculture towards large intensively farmed monocultures there has been a trend away from old traditional methods of pest control (crop rotation, use of native varieties, stalk destruction, etc.) to more unilateral approaches utilizing large quantities of chemical pesticides. With some crops, pest control has evolved to the point that chemical pesticides are used as the only means for protecting the crop from certain pests or pest complexes.

Chemical control, in many instances, has been applied in an attempt to achieve total elimination of the pest of concern from a crop. Thus, it should not be surprising that the pests have adapted to these measures in various ways. There has been widespread development of insecticide-resistant strains of the world's most important crop insect pests, and herbicide use often has resulted in the replacement of one major weed species by another that is just as noxious. In addition, the intensive use of pesticides has resulted in contamination of the environment, damage to non-target species and major disruptions to the ecosystem.

In retrospect, we now know that complete reliance for crop protection on a single component control program has seldom succeeded over the long term. For this reason, knowledgeable plant protection specialists are leading the return to systems of pest control that utilize a combination of methods -- chemical, cultural, biological and physical -- for keeping pest populations below crop-damaging levels. This is a system of pest and crop management that entomologists describe as integrated pest management.

The control of crop pests is an exercise in applied ecology. A broad understanding of the agroecosystem and how it works is essential to the successful integrated pest management program. In case of insects, entomologists have developed the "key" pest concept with the general principle that a key pest is one that occurs every year and for which control must be exercised if crop losses are to be prevented. Contrasted to this is the secondary pest that generally does not cause yield losses unless released from natural biological control through destruction of its natural enemies. The development of economic injury levels then are essential to the integrated control of insect pests. Insecticides seldom are applied until the pest insect population reaches yield-damaging numbers. This is done in an attempt to minimize insecticide treatments, to conserve insect natural enemies and avert the induction of secondary pest outbreaks.

The key pest concept and use of economic injury levels may not have as much application to control of plant pathogens or weeds as to insects. If one key weed species is removed from a crop, its habitat may be occupied by another weed that is just as severe a pest. For certain pathogens, prophylactic measures must be applied before the plants are exposed to the initial inoculum. For this reason, the key pest and economic threshold concept may not always apply to the control of certain weeds and plant pathogens. In other cases, these concepts do apply and should be used.

There are certain features of integrated pest management that are common to the control of arthropod, phytopathogenic and weed pests: Pest control should always be applied in the context of the total agroecosystem. Measures applied for the control of one pest should not increase the incidence of another. A combination of suppression measures should be utilized, whenever possible, to suppress the pest of concern while producing the least damage to pest natural enemies. Lastly, the control system should assure good yields, be economically sound and produce the least contamination of the environment.

The protection of crops from pests requires a blend of disciplinary talents with inputs from entomologists, plant pathologists, weed scientists, engineers, physiologists, agronomists, geneticists, chemists, and economists. The development of the best pest control systems for crops that are grown on vast acreages and throughout the world also will require cooperation among research institutions and governments since pests know no political boundaries. The improved knowledge of the agroecosystem that may be gained from interdisciplinary study offers the greatest potential for improvement of crop protection in the future. New inputs in terms of selective pesticides, biological control and resistant crop varieties may best be attained through cooperative efforts among the agricultural disciplines and among nations. The problems of food production and preservation of environmental quality are truly ones of global concern and the solution depends on international cooperation.

It is in this spirit that the present conference on the integrated control of crop pests of great importance to the United States and the Union of Soviet Socialist Republics is being held. Among the participants are the most knowledgeable pest management experts of our two countries. Each of us is aware that there is no single material or combination of measures presently available that will completely eliminate, or eradicate, the crop pest problems that affect our countries. Thus, the purpose of the present conference is not to present the ultimate solution for any plant pest problem. Rather, the conference offers a platform for the presentation of knowledge of the various ecosystems of concern -- cotton, sorghum and deciduous fruits -- and for gaining a better understanding of how each system responds to natural and introduced variables.

Lastly, we must realize that this knowledge is of little practical value until it is implemented on the farm. Thus, one of the most important aspects of the present conference will deal with the problem of how integrated pest management systems are implemented.

The development of the integrated pest management technology and its transfer to the farm manager is the key for reducing pest losses, increasing crop yields and preserving the quality of the environment. The proceedings that will be issued from the present conference, the acquaintances that will be made and the understandings that will be gained from our contact with one another should provide a mechanism for hastening the solution of immediate problems of mutual concern. The friendships made, hopefully, will provide a vehicle for future cooperative work on agricultural problems of international significance. This can be of benefit to everyone.

A

Sorghum Pest Management

SUPPRESSING WEEDS IN SORGHUM

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Sorghum production in the United States is located primarily in the Southern Great Plains area between the Rocky Mountains and the Mississippi River. Texas grows half of the crop, or 8.1 million acres. Other states that grow more than 1 million acres are Kansas, 4.7 million acres; Nebraska, 2.2 million acres; and Oklahoma, 1.1 million acres. Colorado, New Mexico, Missouri, Arizona and California produce 0.5 million acres or less of the crop. About 3 million acres of sorghum are irrigated, primarily in the Panhandle of Texas.

Twenty-five years ago, cultivation and crop rotation were the only weed control methods available for suppressing weeds in sorghum. Weeds are very competitive because sorghum has a relatively small seed, and its apparent growth rate after planting is slow until it develops a large leaf area. In many cases, if weather prevented cultivation of small sorghum, replanting was necessary.

Wild sorghum or shattercane (*Sorghum bicolor* [L.] Moench) is the worst annual weed in the crop because herbicides that kill this pest also kill sorghum. Barnyardgrass (*Echinochloa crusgalli* L. Beauv.) is a problem in central and northern sorghum fields. Green and yellow foxtail (*Setaria* sp.) are problem grass weeds in the northern sorghum producing area. Broadleaf signal grass (*Brachiaria platyphylla* [Griseb.] Nash), crabgrass (*Digitaria* sp.), brown top panicum (*Panicum fasciculatum* Swartz) and Texas panicum (*Panicum texanum* Buckl.) trouble sorghum growers in Central and South Texas. Problem grass weeds can only be controlled with a combination of herbicides and cultural practices. Several species of pigweed (*Amaranthus* sp.) grow wherever sorghum is planted but are easily controlled with herbicides.

Several researchers have conducted studies to determine the effect of various weed populations on sorghum yield. Studies at the USDA Research Center at Bushland showed that one pigweed in 32 feet of a 40-inch row cut irrigated sorghum yield 10 percent. If potential yield is 5,000 pounds per acre, this amounts to 500 pounds of grain worth about 15 dollars per acre. One pigweed per foot of row cut yield 50 percent. It is usually profitable to use herbicides and control the last few weeds in a field.

Perennial weeds are very competitive and may reduce crop yields from 50 to 100 percent depending upon management. Johnsongrass (*Sorghum halepense* [L.] Pers.) and field bindweed (*Convolvulus arvensis* L.) are the two worst perennial weeds that plague sorghum farmers. It is impossible to grow profitable sorghum crops on land infested with Johnsongrass. Bindweed is very competitive but can be controlled with 2,4-D at 0.5 pound per acre when bindweed plants have 6- to 10-inch runners and sorghum is at least 6 inches tall. Common milkweed (*Asclepias syriaca* L.) is a perennial weed that is troublesome in the northern part of the sorghum growing belt. Woollyleaf bursage (*Franseria tomentosa* Gray) and Texas blueweed (*Helianthus ciliaris* DC.) are troublesome perennial weeds in the southern part of the sorghum belt that cannot be controlled in the crop.

Herbicide Development

The history of herbicide development in sorghum gives insight into weed control techniques available for farmers. The phenoxy herbicides, 2,4-D and MCPA[1], were proven safe and effective in the early 1950's. Each year several million acres of sorghum are sprayed for broadleaf annual weed control with these herbicides.

Propazine was first evaluated as a preemergence herbicide in 1957. After 5 years of testing this herbicide was labeled and ready for farmers to use. It was the first herbicide that would control both broadleaf and grass weeds in sorghum. Shortly after propazine was labeled, atrazine was evaluated as a postemergence herbicide for sorghum. Atrazine applied in a nonphytotoxic oil-water emulsion spray carrier usually controlled both grass and broadleaf weeds. It was most effective on grass weeds if rainfall occurred within 1 week after application.

In 1968 and 1969, the feasibility of applying atrazine and propazine by air was determined. The results showed that the herbicides could be applied in as little as 1 quart of carrier for each pound of herbicide. At about the same time, dicamba, a postemergent herbicide, was proven effective and safe for controlling broadleaf weeds. It was safer to use near cotton than 2,4-D.

Five years ago, barnyardgrass became a difficult weed problem in the Panhandle of Texas. Farmers used 2,4-D or low rates of propazine and, frequently, no cultivation. This allowed barnyardgrass to become the dominant weed in many fields. Preplant, preemergence and postemergence herbicides were combined with cultivation to attack the weed. Propazine at

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1/Herbicide names used are those designated as common names by the Weed Science Society of America.

3 pounds per acre was applied up to 1 month before planting and incorporated with a rolling cultivator. Then fields were irrigated before planting. This procedure resulted in good control of barnyardgrass. If it rained within 2 weeks after planting, propazine applied at 3 pounds per acre immediately after planting (preemergence) was also successful. High rates of Terbutryn alone or propazine mixed with either linuron or propachlor also controlled weeds when applied preemergence, if it rained within 2 weeks after planting.

Researchers in the United States doing most of the weed control research in sorghum are J. R. Abernathy, Texas A&M University Agricultural Research and Extension Center, Lubbock, Texas 79401; Orvin C. Burnside, Department of Agronomy, Univeristy of Nebraska, Lincoln, Nebraska 68503; C. W. Helpert, Texas A&M University Agricultural Research and Extension Center, Rt. 5, Box 784, Beaumont, Texas 77706; M. G. Merkle, Department of Soil and Crop Sciences, Texas A&M University, College Station, Texas 77843; W. M. Phillips, Ft. Hays Experiment Station, Hays, Kansas 67601; P. W. Santlemann, Department of Agronomy, Oklahoma State Univerisity, Stillwater, Oklahoma 74074; and Mr. Gail Wicks, University of Nebraska, Norht Platte Station, North Platte, Nebraska 69101.

Limited Tillage

Over the past 5 years, the author has cooperated with Paul Unger, Jack Musick and Ron Allen, USDA researchers at the Southwestern Great Plains Research Center at Bushland, on limited tillage studies. Planting sorghum without tillage into sorghum stubble from a previous year is impractical because volunteer sorghum is not adequately controlled with herbicides. If volunteer emerges along with the planted sorghum and stands are too thick, forage yields are high and grain yields are lowered compared with conventional tillage.

Double-cropping sorghum after wheat harvest is feasible when no tillage planting is used. Sorghum can be planted in wheat stubble the day of harvest and furrow irrigated immediately for emergence. Atrazine can be used to control weeds and volunteer wheat after sorghum emerges. This system is faster than regular tillage and sorghum is seldom hurt by frost. Sorghum plants protected by stubble grow off faster than those on bare soil. In a 5-year study, no-till planted sorghum yielded 500 pounds per acre more than conventionally planted double-crop sorghum.

A limited tillage system in a wheat-sorghum-fallow cropping system has been perfected. Wheat stubble is maintained intact and weed free with 2,4-D and atrazine during the 11-month fallow prior to sorghum planting. Soil moisture storage during the fallow has been doubled in most of these experiments compared with regular tillage. As a consequence, subsequent grain sorghum yields are increased about 1,500 pounds per acre by the extra soil moisture. In the fallow period between sorghum harvest and wheat planting, reduced tillage cut production cost and increased yield.

Summary

There are good cultural practices and excellent herbicides for controlling weeds in sorghum. Propazine can be used preplant or preemergence. Terbutryn alone and linuron or propachlor mixed with propazine can be used preemergence. Farmers can select postemergence herbicides to suit their locality and weed species. Dicamba, MCPA and 2,4-D will control broadleaf weeds. MCPA and dicamba are safer to use near cotton than 2,4-D. Diuron and atrazine are postemergence herbicides that are safe to use near cotton, and both have soil residuals to control weeds that emerge after treatment.

MEASURES FOR CONTROLLING DISEASES OF SORGHUM

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Sorghum is a relatively healthy crop in the United States. If it were not, farmers soon would refuse to grow it. In addition to inherent resistance of sorghum to diseases, there are two principal reasons for minimized disease losses: 1) most of the crop is grown for grain in a climate that generally is unfavorable to most sorghum pathogens; and 2) disease control measures, developed through integrated research programs and executed by an extremely capable agricultural industry, usually have neutralized serious disease threats.

Nevertheless, sorghums in the United States are not without vulnerability to diseases. The number of major pathogens is not great, but several hundred microorganisms or entities are known or suspected to be sorghum pathogens. Almost all major sorghum pathogens have been introduced, although we have at least one pathogen that is unique to our country.

Genetically, sorghum probably is as vulnerable to diseases as any cultivated crop. From the extensive genetic diversity among sorghums at the centers of origin, we have used relatively few introductions to develop the varieties and hybrids being cultivated in the United States. To a large extent, genetic uniformity has been intensified because of production economics. Margins of profit to farmers is very narrow. Therefore, they demand sorghums having the greatest yield potential. To satisfy those demands, competitive seed companies have had to use several germplasms in common. For example, the origin and perpetuation of the seed industry comes from discovery and use of sterility-inducing milo cytoplasms that made production of hybrid sorghums possible. Another example of intensified genetic vulnerability is the extensive use currently being made of yellow endosperm germplasm in hybrid sorghums.

Some aspects of crop ecology also increase vulnerability of sorghum to diseases. Concentration of grain sorghum in the Great Plains presents airborne pathogens with a supply of host plants that is uninterrupted by natural barriers to air currents. Prevailing winds favor dispersal of those pathogens in the same direction as seasonal development of the crop. Dispersal of seedborne pathogens is made possible by in-transit loss of grain from inter- and intrastate shipments of sorghum destined for domestic consumption and for export. Soilborne pathogens that cause root and stalk rots probably are enhanced by several production methods, such as use of short or no rotations, heavy nitrogen fertilization, high planting rates and mechanical tillage with heavy equipment.

The strategies used for controlling sorghum diseases perhaps can be illustrated best by concentrating this discussion on methods used to control six or seven major pathogens that have caused serious losses in the United States. Some control measures have essentially eliminated the diseases for which they were developed, while others have been temporarily or partially effective. The resources available for development of control measures, however, represent a formidable arsenal for defence of the crop against potential as well as currently important sorghum pathogens.

Chemotherapeutic Control

For all practical purposes, control of sorghum diseases by chemical means has been restricted to treatment of seed. Such treatment virtually eliminated kernel smut (*Sphacelotheca sorghi*), the first serious disease of sorghum in the United States. The effectiveness of seed treatment for controlling kernel smut, as well as for minimizing seed rot and seedling blight, has been fully realized, since farmers universally accepted commercially produced and processed seed. Before that, control of kernel smut was not always complete. The safest, most effective fungicides currently used are nonmercurial organic types such as thiram or captan. Application is usually made by the slurry method, but even safer treatments are foreseen in newer methods, such as flowable formulations and seed-coating processes.

Other than seed treatment, the potential for chemical disease control is uncertain. In recent years, several systemic fungicides having fungicidal specificity have been developed. For example, those specific for root pathogens such as *Pythium* or *Rhizoctonia* sp. could be useful if costs of application are realistic. Another possibility we may have to consider is the aerial application of protectant fungicides for control of head molds that have been troublesome in certain areas. Public awareness of potential environmental hazards, however, probably will discourage use of all but the most essential chemotherapeutic measures.

Genetic Control

Resistant cultivars represent the principal method of controlling sorghum diseases in the United States. Demonstrable host specificity among the pathogens, vast crop areas and small profit per crop unit logically favor that option. Three basic resources are required to develop disease-resistant cultivars: 1) collections of germplasm to stockpile genes for resistance, 2) screening tests to identify and evaluate potentially useful resistances, and 3) breeding programs to incorporate selected resistances into desirable genotypes.

The United States is fortunate to have had several pioneer sorghum breeders who maintained diverse germplasms throughout their long careers. Those genetic stocks have been preserved by their successors and have been used to provide most of the resistances presently found in varieties and hybrids. Other sources of resistance are being evaluated. Recent recognition of the need to preserve genetic diversity in sorghum was manifested by the establishment of a World Sorghum Collection. Our breeders have made extensive use of this collection, now containing over 16,000 entries, especially through a Sorghum Conversion Program in which tropical day-sensitive sorghums are converted to day-neutral types that can be used for breeding objectives in the northern latitudes. Multigenic resistances to individual diseases and combined resistance to several diseases appear to exist among many exotic types in that collection. Consolidation of such resistances into wide-base germplasms could help minimize the potential problem of genetic vulnerability in sorghum.

To identify resistances, reliance has been heavily placed on natural or induced infection by specific pathogens in strategically located screening tests. These tests have been maintained by growing susceptible sorghums on sites with histories of unusually high incidences of one or more major diseases. In recent years, screening efforts probably have been concentrated most in Texas.

Head Smut

Losses from head smut (*Sphacelotheca reiliana*) and sorghum downy mildew (*Sclerospora sorghi*) in the Coastal Bend Area of Texas, and potential losses elsewhere prompted The Texas Agricultural Experiment Station to establish several screening nurseries near Beeville, Texas. Using those nurseries, usable resistances were found to three of four head smut races thus far identified in this country. Presently, we are searching for resistance to the recently identified fourth race.

Sorghum Downy Mildew

Resistance also has been found to sorghum downy mildew, principally among converted World Collection entries. A promising new method for screening sorghum for resistance to downy mildew has been developed that involves inoculation of seedlings with conidia and evaluation of systemic infections under greenhouse conditions.

Maize Dwarf Mosaic

Initial screening tests for maize dwraf mosaic, the first major virus disease of sorghum, also were established in South Texas. In recent years, however, that disease has spread sufficiently to establish screening tests at home stations of several plant breeders in the southern half of the United States. The pathogen, sugarcane mosaic virus strain J, overwinters in johnsongrass, a perennial weed host, throughout its distribution south of the Ohio and Platte River valleys. The principal vectors, corn leaf aphids (*Rhopalosiphum maydis*) and greenbug aphids (*Schizaphis graminum*), spread the virus to essentially all sorghum fields in proximity to johnsongrass each season. Present resistance significantly reduces the severity of both the mosaic and necrotic reactions to virus infection. Resistance approaching immunity among the Krish sorghum derivatives released by Australian workers is being evaluated for use in our breeding programs.

Anthracnose

Anthracnose screening tests also are conducted among field nurseries. Natural infection is used effectively by breeders in Georgia, and supplementary inoculum in form of pulverized diseased tissues is put into whorls of young plants in screening tests in Mississippi. Developing anthracnose-resistant grain sorghums is difficult because resistance tends to dissipate as the grain matures. However, promising mature-plant resistance has been noted in lines derived from crosses between grain sorghums and anthracnose-resistant sweet sorghums. Considerable resistance also has been identified among converted World Collection entries.

Periconia Root Rot

For many decades *Periconia* root rot, caused by *P. circinata*, has been controlled with simple, incompletely dominant resistance. Theoretically, however, *P. circinata* has the capacity to develop strains specific for germplasms common to large portions of the crop, and therefore, it could jeopardize our best hybrids. Most species of *Periconia* are saprophytes; only *P. circinata* has been associated with a root disease. That disease has not been found outside the United States. Unlike most root-infecting fungi of sorghum, *P. circinata* evolved a unique strain that was pathogenic by virtue of producing a toxin specific for milo sorghums. Field tests, or greenhouse tests with infested soil, were used to develop resistance to the disease. Field tests still are used to monitor the pathogen among modern varieties and hybrids. For large scale screening, however, a better method has been developed in which toxin is extracted from pure culture filtrates and used to test young sorghum seedlings under laboratory conditions.

Cultural Control

Success in disease control achieved with seed treatment and host resistance has not eliminated severe losses from root and stalk rots. Clear-cut resistance to these diseases has not been found, probably because the associated organisms (*Fusarium*, *Pythium*, *Sclerotium* and *Rhizoctonia* sp.) lack host specificity. Activity of these soil inhabitants depends on rhizosphere environment at various stages of host maturity. Compared with an undisturbed native prairie soil, our cultivated soils have lost up to 50 percent organic matter and have increased in bulk density at least 30 percent. Under these conditions roots become subjected to increased physical resistance of the soil, reduced availability of oxygen and water and reduced dispersion of toxic gaseous and liquid exudates from roots. Sorghum plants then become predisposed to attack by root-infecting fungi. Root and stalk rots are being evaluated under various crop management systems at many locations throughout the Great Plains. Present evidence suggests that we may be able to reduce susceptibility by use of minimum or zero mechanical tillage where crop residues are left on top of the ground perennially.

Quarantine Control

Until recently, use of quarantines to prevent import of diseased or infested sorghum seed was rare; this probably accounted for the introduction of many sorghum pathogens into the United States. Currently we are enforcing quarantines on sorghum seed from Africa and southeast Asia to reduce chances of introducing potentially damaging sorghum pathogens, such as *Sphacelia sorghi* (ergot) and *Striga hermonthica* (witchweed). Quarantines can be important in disease control, but concurrently, seed representing germplasms vital to breeding programs must be imported. Such introductions are made by producing seed under containment in facilities approved by the Animal and Plant Inspection Service in the U. S. Department of Agriculture.

Sorghum probably always will have diseases. Like those of other crops, sorghum diseases vary in severity from year to year and from one locality or field to another, depending upon environment, causal organisms and host resistance. Misconceptions of disease control often arise because the interdependency of these factors is not considered adequately in disease appraisal. It is not feasible to eradicate diseases, but minimizing disease losses is easily possible by use of discrete control methods based on thorough knowledge of the nature and etiology of each potentially important disease.

THE INTEGRATED CONTROL OF PESTS IN CORN IN THE U.S.S.R.

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The areas planted to corn in the Soviet Union are stabilized and amount to 22-23 million hectares, of which 3.5-4 million hectares are for use as grain and the rest for silage. The future expansion of land used for growing grain corn is projected at 5-6 million hectares.

The land which is cultivated for corn is far from uniform in type, differing in soil and climatic conditions, and extends over 300 different geographic and agricultural zones -- among them, steppe, wooded steppe, a significant part of the nonchernozem zone, Siberia, the Far East and Central Asia. In the arid regions of the Southern Ukraine, the Northern Caucasus, Transcaucasia, the middle and lower Volga regions and Central Asia, corn has taken a leading place among crops on cultivated lands. The corn belt region in the southern part of the U.S.S.R. has been growing the crop as far back as the 17th century, but the remainder, and major portion, has only been planted to corn within the last 20-25 years.

If one takes into consideration the biological factors necessary for the growth and development of corn, the phylogeny of the species, the requirements of the crop for warm weather, abundant moisture and rich soils and the biotic and abiotic features of regions where corn originated and does well, then compare this with the soil, moisture and climatic conditions of the corn area in the U.S.S.R., it is easily seen that corn is not very well adapted to this country. In the northern regions, corn often suffers from cool temperatures and a lack of moisture during the seedling stage or during the entire growing season. In the southern regions where the climate is sufficiently warm, there is an acute lack of moisture. Therefore, in line with primary objectives, corn breeders and agrotechnicians have directed their efforts toward increasing the yields of grain corn and silage by developing varieties that better tolerate adverse weather conditions and are better adapted to the U.S.S.R.

Among the unfavorable factors adversely affecting corn production, harmful insects and other pests play a major role. Although the types of harmful insects which do damage to corn in the various zones differ, as does the type of damage inflicted on the corn grown for various purposes, the degree of loss due to pests can be quite extensive.

Experience has shown that it is practically impossible to raise corn without an accurately planned system of pest control and prophylactic measures, which mainly include agrotechnical, chemical and, in certain cases, even biological methods of pest control. The application of these methods is based on a knowledge of the biology and ecology of the pests and the natural dynamics of their numbers, together with an estimate of zonal and agro-economic factors. The implementation of a system of measures to combat the pests that damage corn, while observing environmental considerations against pollution and avoiding such agents (insecticides) that could harm humans, animals and useful insects, embraces the principle of integrated control.

The individual species of harmful insects each must be observed and isolated. They must be looked on not only as pests of corn but as ecological components of a corn field where constant and complex interrelationships are developed between those species that attack the plant and numerous parasitic, predatory and indifferent insects, microorganisms and other living things. The number of destructive arthropods in corn throughout the whole of the Soviet Union consists of more than 400 species. Of these, no more than 40-50 species have caused visible economic damage. The economic significance of all the remaining species is minimal as long as they represent a minor threat or inflict incidental damage. Specific, practical control methods exist for not more than 15 or 20 species.

Ecological research on corn has not had a long history and, until recently, has not been discussed in many publications. It has been established that a number of major pests that attack corn are regulated, exclusive of other factors, by natural mortality factors such as several parasitic and predatory insects and pathogenic fungal, bacterial and viral pathogens, all of which may be quite deadly to the pests. For example, some 40 species of parasites are known to prey on the winter cutworm (*Euxoa segetum*). There are more than 20 species of parasites and predators which prey on the cotton bollworm (*Chloridea obsoleta*) and more than 30 entomophagous species which attack corn aphids. The oil fly (*Lydella grisescens*) preys on the caterpillar of the European cornborer (*Pyrausta nubilalis*), affecting up to 45 percent of the pest population. The golden-eyed fly (Chrysopidae), the lady beetles (Coccinellidae), the predatory ground beetle (Carabidae), the water bug (Hemiptera), the rove beetle (Staphylinidae), the Thrips (Thysanoptera), the parasitic Hymenoptera and the flies (Diptera) are constant features of the corn ecosystem.

In addition to the characteristic destructive arthropods harmful to corn, one might note that other pests also exist in the Soviet Union which are widely known and very dangerous in other countries and continents, such as *Pyroderces rileyi*, *Diatraea crambidoides*, *D. grandiosella*, *Chilo zonellus*, *Laphygma exempta* and *Calocoris angustatus*.

Studies of the zonal occurrence of the species of pests harmful to corn, the trophic and ecological relationships of the various species, the nature and degree of their adaptation for infesting corn, the nature of damage to plants and level of losses were conducted by the All-Union Scientific Corn Research Institute (ASRI-corn), the All-Union Scientific

Research Institute for Plant Protection (ARPP), the Zoological Institute of the Academy of Sciences of the U.S.S.R. and other scientific research establishments in this country. These studies have shown that not all the harmful species are newcomers to our country, either before or after corn was introduced (in the 17th century). Some are indigenous local fauna which have adapted to the environment of the corn field, with its specific agrotechnical conditions. Furthermore, not all the harmful species which attack corn are narrowly restricted to this host. Some are polyphagous and oligophagous and may have developed on other crop plants and weeds.

A typical feature of certain corn pests, which is found in nearly all corn-growing regions and particularly in the north where corn is grown only for silage, is that they feed on the newly sown seeds and seedling corn plants. Hence, primary concern is given to pests such as the wireworm (larva of the click beetle) and the false wireworm, the stalk flea *(Phyllotreta)*, the frit fly and the underground feeding worm (family Noctuidae). Pests which attack corn during the later growing periods are of secondary importance. Since corn has been grown in the U.S.S.R. for only a few decades, the adaptive processes of many harmful pests of the crop have not yet had a chance to stabilize and are still in the formative stage.

In the older regions where corn has been grown for some time and is used for grain as well as for silage (Moldavia, Ukraine, the northern Caucasus and the Far East), certain soil-inhabiting seed and seedling pests represent a serious threat to the crop. In the southwest regions of the country, the southern grey weevil (*Tanymecus dilaticollis*) also is a serious pest. Pests that feed on leaves, stems and reproductive organs are the cornborer, the cotton bollworm, the corn worm (*Sesamia cretica striata*) and sucking pests of the order Homoptera. The prevalence of basic pests and the degree of their harmfulness per individual corn region are governed by many zonal factors which are directly related to the measures required for their control.

The present-day state of biological studies, the factors of numerical dynamics, feeding and other ecological relationships among harmful insects in the corn ecosystem and the level of research studying eradication and prophylactic control techniques has made it largely possible to avert crop damage by pest insects. Basically, control of corn pests calls for a number of complex agrotechnical, chemical and biological control methods aimed at the destruction of harmful organisms, the establishment of ecological conditions unfavorable to pest development and the reinforcement of genetic or biological stability of the plant vis-à-vis the insect. In recent years, scientific research on protecting corn from pests and its practical implementation on the production level has placed greater emphasis on reversion to the principles of biological control, which looks not only at protecting the plants and the harvest but also at preserving ecosystem integrity.

The application of this classical complex system of plant pest control, as developed by V. N. Schegolev, G. Ya. Bey-Bienko, A. V. Znamensky,

N. N. Bogdanov-Kat'kov, N. I. Arkhangel'sky, K. P. Gribanov, I. M. Belyaev and many other Soviet entomologists of the pre- and postwar eras has made it possible to increase significantly the economic effectiveness and biological rationale for every measure. Corn as a crop does not have the highest rate of adaptability to an integrated control system when compared with, for example, vegetable or fruit crops. Nevertheless, an analysis of the measures developed by science and employed in production has shown that the majority of the control procedures are being carried out, or can be carried out, in compliance with the demands of integrated control. This is particularly true for closely related agrotechnical measures.

The majority of agrotechnical methods used in growing corn are directly related to and used as a means of controlling pest insects and diseases, by acting indirectly to increase the plant's tolerance to damage. It is possible to cite several examples on this score. The use of cultivation against the winter cutworm, trapping the cutworm moths with fermented syrup and the suspension of corn planting in regions greatly threatened by the southern grey weevil, are measures which act directly only on the pest, with little effect on other elements of the corn ecosystem. The necessity of either carrying out these or other agrotechnical methods and of observing them for a fixed period of time calls for creating better conditions for plant growth and development. A related approach is to increase a plant's ability to tolerate injury. Under good agrotechnical conditions, the development of many harmful insects may be suppressed, and several methods (plowing, cultivating, combine-harvesting) immediately destroy them. Due to the pivotal role of agrotechnical methods, it may also be concluded that with well-developed plants, protective or exterminative control measures become more effective.

The introduction of proper crop rotation makes it possible to plan in advance and establish agrotechnical and chemical control measures against a number of multi-host pests, not only on fields planted to corn but also on cleared or plowed fallow land, on crops already bearing ears and on the fields planted with a rotation crop. Although a fallow period does not always precede the planting of corn, this is one of the best means to control the cutworm. The cutworm moth also may be trapped with fermented syrup without disrupting the ecosystem as a whole. These methods provide protection of corn from this pest. In regions severely threatened by the southern grey weevil, one way of decisively preventing damage by this pest is to alternately rotate corn with another crop.

The use of fertilizers also affects entomophagous and harmful insects which thrive in the cornfield. It has been experimentally shown that the damage to corn inflicted by the frit fly and several other pests occurs less frequently in fields where organic or mineral fertilizers have been used. At the Izmail Experimental Station of ARRI-Corn between 1962 and 1965, 16.1 percent of the corn on a field fertilized with granulated super-phosphate was injured by the frit fly, while the loss on an unfertilized field was 22.1 percent. By introducing nitrogen, phosphorous and other mineral fertilizers on a number of corn fields at the experimental research institute, the damage caused by the frit fly was 43.7 to 46.2 percent less than on an unfertilized field. These data show that of the damage done by this pest there was a loss of 41.7 percent of ears on unfertilized plants, an 11.9-percent loss among those fertilized with super-phosphates and a 9.3-percent loss when fertilized with manure. Applying nitrogen fertilizer to corn resulted in more rapid plant growth and a "self-cleansing" of the plants from the larvae of the frit fly which actually killed the pests.

Tilling the soil also directly decreases the numbers of the frit fly, the wireworm, the cutworm, the cotton bollworm, the *Lamelli corniferous* (a Carabidae larva), the *Lethrus apterus* beetle, corn aphids and the beet webworm (*Loxostege sticticalis*).

Naturally, in any land cultivation the formation of monocultures over large areas with a limited number or a single type of plant, in conjunction with periodic mechanical turning of the tilled layers of soil, does not lead to an increased interaction between natural communities. It has been found, however, that with existing methods of tillage it is comparatively easy to drive plant parasites and predators out of the soil, especially those that are not soil-related in their development. Tilling the soil as a means to control weeds has an indirect effect by also controlling pest insects.

A control program that does not adversely influence the corn ecosystem must consider the time and period for planting the crop and its care during the vegetative period. Well-timed planting during a short period of time ensures a rapid and simultaneous growing of the young plants. The more rapid the growth of the plants during the seeding stage, the greater the increase in plant tolerance and the shorter the period during which early season pests may inflict damage. The caterpillar of the cutworm is most dangerous when it attaches itself to a young plant. The wireworm may also be a serious pest during early planting, or during the period between planting, sprouting of the seeds and the actual development of the plant into 4-5 leaf stages. With optimum planting periods, the plant also suffers less damage from the stalk moth, cotton bollworm and *Phyllotreta vittula*.

The destruction of weeds, whether by cultivation or by use of herbicides, results in a decrease in the number of multi-host pests, for example, the cutworm, the cotton bollworm and the southern grey weevil.

In the southern U.S.S.R., the area of irrigated corn is constantly expanding because of insufficient and unreliable patterns of rainfall. The introduction of irrigation, however, changes the microclimate, increases the moisture of the soil and lower air layers and increases the temperature in the corn leafage. Irrigation may create several new conditions, causing the number and destructiveness of some harmful insects to increase and others to decrease. Irrigation ditches become habitats for several of the life stages of certain pests. When irrigation ditches and plowed ridges are full of moisture, up to 90 percent of the hibernating pupae of the cotton bollworm may be destroyed. The vegetational irrigation of corn, carried out during final cultivation which is simultaneous with the pupation stage of the cotton bollworm, kills many pupas through the flooding and destruction of their soil passages and nesting holes. This partially inhibits the development of a generation of moths the following summer.

Large numbers of winter cutworm caterpillars are also destroyed when vegetational irrigation ditches, replete with moisture, are established. Irrigation of ditches is particularly effective during the primary developmental period of the caterpillar.

By increasing soil moisture, the eggs of the darkling beetle are destroyed as are the larvae of the false wireworm, both of which are harmful to corn in the southern regions of the country.

On irrigated lands, increases in the numbers of several moisture-loving pests have been observed. Among these are the click beetle, the mole cricket, the frit fly, the spring grain aphid and the European cornborer.

Under irrigated conditions, the critical question of weed control becomes most important. This also has a direct relationship to utility as a means of controlling certain other pests.

Specialized literature has insufficient information on the experimental analysis of the effect of irrigation on entomophagous species in the corn ecosystem. Some data, however, has been obtained from experiments with other crops (winter wheat, sugar beets, cotton, vegetables) which favors irrigation in such a plan. In other words, irrigation as a crop improvement method, in this case, may be seen as an ecological factor which fulfills the requirements of integrated control.

There can be no doubt about the high effectiveness of control, as reflected by the quality of the harvest when combating the European cornborer, the cotton bollworm and other harmful insects. The caterpillar of the cornborer feeds on the stalk and gradually moves from the upper portion of the plant to the lower, and one month before harvest, 31.4 percent of the caterpillars are in the sheaths of leaves and panicles and 68.3 percent in the midsection of the stalk, the ears and the stems of the ears, while almost none are found in the lower part of the plant. When fully mature, almost all of the caterpillars (92.7 percent) may be found in the lowest section of the stalk which remains in the field after harvesting. Hence, the height at which the stalk is cut during harvesting is of crucial importance. In stubble 20 cm high, 5.3 percent of the caterpillars were left in the uncut stalk, but when the height of the cut was raised to 30 cm, the number of caterpillars increased by 51 percent. If stalks are correctly cut when harvesting for silage during the milk-wax or wax stage of maturity 75-100 percent of the cornborers and the cotton bollworms may be killed.

From the data presented it may be concluded that a well-timed corn harvest and a low cutting of the plant provide an excellent means for controlling the cornborer. There is no doubt that this kind of harvesting operation will have some destructive effect on those parasites which during the harvest season continue their development in caterpillars residing in the cut stalks.

In summing up the significance of agrotechnology in the control of corn pests, it should be emphasized that these methods are aimed directly against harmful insects, producing a decrease in their numbers, and thereby protecting the yield from loss and increasing the plant's tolerance and resistance against pests. Integrated control methods normally do not show any great adverse effects on other insects, and particularly not on useful insects. This system of control is the most widely used in corn and assures high effectiveness. It can also be carried out in corn at low cost and with few complications of an organisational or economic nature.

In recent years in the Soviet Union and in a number of foreign countries, research has been broadened on the nature and formation of genetic and physiological tolerance in corn plants to pests. In several cases, the results of this research has been found to be applicable to actual corn production. With respect to plant tolerance to pests, it should be pointed out that, as an element of an integrated control system, the differential tolerance of corn varieties and hybrids to pests is not a passive feature in the agroecosystem. Instead it has become an important factor in establishing the number and economic status of the various pests. Among the harmful pest insects in corn, certain are distinguished by a fairly broad scale of nutritive habits. There is no reliable protection from any of these species obtainable through complete plant tolerance. The use of additional, special control measures may be required.

Today in the majority of corn-growing regions of the U.S.S.R., corn hybrids are grown on a regional basis and are distinguished by a high and complex tolerance against basic pests, such as wireworms, cutworms, frit flies and cornborers. Furthermore, the growing of many hybrids with moderate tolerance to several of these pests, particularly in the zones acutely threatened by them, has made it possible to reduce the amounts of chemicals required to protect the crop.

The importance and future prospects of the use of pest tolerance in corn also takes into account the realistic possibility of developing and breeding new lines of corn with the ability to tolerate a specific or several species of pests, including a complex of pest insects and diseases. The widespread utilization of tolerant corn hybrids having other agriculturally useful characteristics has a tremendous economic and ecological advantage and, to a significant degree, will bring about an improvement in the environment and prevent the pollution of agricultural produce.

Chemical control procedures presently used against many harmful insects of corn in some cases does not meet the requirements of integrated control. However, the establishment of specific methods of chemical treatment and the development of new chemicals to be used in a selective, systematic approach, as well as improvements in other pest suppression techniques, will make it possible to limit or even to completely eliminate the hazardous effects of poisonous chemicals on man and his environment.

Among the pests against which chemical control measures are regularly used are the wireworm and the false wireworm, underground feeding worms, the frit fly, the southern grey weevil and the cornborer. Sporadic and local needs may arise which require the use of insecticides to control the beet webworm, the corn beetle (*Pentodon idiota*), the *Lethrus* beetle, the cotton bollworm, the mole cricket, the spring grain aphid, the leaf beetle (*Lema melanopa*) and the *Phyllotreta vittula*.

A survey of methods of chemical control which have been developed for control of corn pests within the last decade and currently are actively used in the field shows that many of them have only limited or no detrimental effects on the environment. The new technological control methods replace total measures, such as the unilateral dusting or the spraying of the entire crop, should one of the many different harmful species of insects invade a neighboring field or a sheltering strip of trees.

Seed treatment has been found to be a highly reliable method for controlling the wireworm, the false wireworm and other soil pests which are threats in almost all of the regions where corn is cultivated. The use of preplant treatment of seeds with toxic chemicals (for pests and diseases) such as Fenticor, TMTD (thiram) with heptachlor or with gamma-isomer hexachloride (lindane-BHC) and heptachlor (for insect pests only) makes it possible to apply insecticides in such a way that they affect only the seed and an insignificant area of soil surrounding the seed. By mixing 2 kg of the chemical to one metric ton of grain, 2 kg amounts altogether to 40 g of toxic material per hectare. Such a quantity certainly does not present a serious threat to other organisms in the soil which live in the same habitat as insects.

The regular spreading of hexachloran (BHC) onto the soil at a standard rate of 10 kg per hectare would in such a large amount, of course, threaten the soil ecosystem. It would not be used on all fields, however, only on those infested with large numbers of pests. The further discovery of new, more effective toxic chemicals for preplant seed treatment should make it possible in the future to forego this method entirely and, thereby, completely eliminate the harmful impact of chemicals on the environment.

A green bait formulated with heptachlor or gamma-isomer hexachloride is used against the southern grey weevil and the caterpillar of the winter cutworm. Although this method is time-consuming, thereby restricting the extent to which it can be used, its direct effect on the entomophagous species of the corn field is minimal. Insecticide baits such as this have a place in the integrated control of corn insect pests.

When the cornborer reproduces in large numbers, the heavy use of toxic chemicals is required. Earlier (in the ASRI-Corr), the procedure for use of insecticides (dosages, periods, consistency) were worked out, but these methods did not protect the entomophagous species from injury. The development of a new granulated form of chlorophos has increased the effectiveness of chemical control and allowed for considerably more precision for placing the insecticide exactly in the area where it is needed. Instead of totally saturating the entire surface of the corn foliage with toxic substances, which would kill both pest and the majority of beneficial and neutral insects, the use of granulated chlorophos would be limited to merely depositing the granules on the axillae and veins of the leaves. This is the area of the plant where newly hatched caterpillars of the cornborer or other insects may be expected to be found with certainty.

In certain years in humid regions and also on irrigated lands, aphids increase in great numbers and inflict tremendous damage to corn. Destroying them with insecticides usually is not difficult, and the most biologically expedient method of control is the use of a system of chemicals. To protect corn from aphids, therefore, it is wise to use phosphamides in greater amounts.

Of course, in some cases under present circumstances, the necessity of treating the entire crop with insecticides to protect against a number of pests exists. The rational procedure for the control of these pests and the need to protect the environment require a limited use of insecticides. This calls for the development of new means of selective and other systematically different actions that will affect only the pests.

The elaboration of the proper criteria to follow in the control of harmful insects and development of quantitative levels and times when an insect becomes a pest will make it possible to increase the operational effectiveness of chemical control. The frequency and volume of treatment also may be limited.

In the modern practice of controlling corn pests, a limited use of biological methods may be utilized. A number of concrete examples can be cited: use of *Trichogramma* sp. against the winter cutworm, the cotton bollworm, the European cornborer and the beet webworm, and dendrobacilline against the cotton bollworm. Moreover, in recent years biological control methods against harmful insects has gained more importance and is being slowly perfected. On the whole, a significant expansion in research on use of biological methods and the study of insect sterilants, attractants and hormonal preparations is occurring.

In conclusion, the control of corn pests has reached a point of transition from single component control methods to a system of integrated control procedures which includes a rational combination of agrotechnology, the use of tolerant hybrids, the use of entomophagous species and the use of chemical compounds. The combined application of these measures make it possible to preserve the greatest number of useful insects to protect the yields of corn and to prevent damage or injury to the environment and man.

INTEGRATED CONTROL OF ARTHROPOD PESTS OF SORGHUM

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Formulating integrated pest management strategies in sorghum revolves around the key pest or pests. Key pests are the more economically damaging, perennially occurring, persistent species for which most insecticidal control is applied. In the case of grain sorghum, the greenbug, *Schizaphis graminum* (Rondani), and the sorghum midge, *Contarinia sorghicola* (Coquillet), are the key pests. In contrast to key pests, secondary pests, though possibly present most of the time, cause economic damage only at certain restricted times and generally are not the focal point of an insect control program. A significant fact is that outbreaks of secondary pests are often triggered by unilateral insecticide treatment for a key pest. In the case of grain sorghum, spider mites -- especially the Banks grass mite, *Oligonychus pratensis* (Banks) -- may be considered a secondary pest; however, once this mite is released from natural control it may cause more damage to the crop than the key pest. Other insect pests in grain sorghum, such as the corn earworm, *Heliothis* sp.; fall armyworm, *Laphygma frugiperda* (J. E. Smith); false chinch bug, *Nysius* sp.; white grubs, *Phyllophaga* sp.; sorghum webworm, *Celama sorghiella* (Riley); and several species of root and stalk borers only occasionally require insecticidal control. These species are lumped into the category of occasional pests. But it is important to realize that an outbreak of these pests can destroy a management strategy that does not take them into account. Research-wise, they are extremely important.

The principles of integrated control are sound for any crop in any location, but of course, the pests involved may be different. The basis for the management strategy in sorghum is developed around the greenbug and the sorghum midge, which are the key pests in Texas.

Key Pests

Sorghum Midge

The sorghum midge may be the most cosmopolitan pest of grain sorghum (4). Damage to Texas grain sorghum by this insect pest has been estimated at more than $10 million annually (25). In many sections of the state where the sorghum midge is especially abundant, as much as one-fifth of the crop may be destroyed each year. Damaging infestations of the midge generally develop after two or three consecutive midge generations in grain sorghum (6). Late-planted grain sorghum blooming after the development of these damaging infestations usually suffers heavy yield losses (8).

The sorghum midge adult is a small gnat-like fly, usually orange in color, that lays its eggs on the developing seed of blooming grain sorghum. Larvae feed on the developing seed and cause "blasting" of the heads (9). The life cycle is short, only about 18 days being required for a generation. Each adult may lay 50 to 250 eggs during her 24-48-hour life.

Since the development of damaging infestations of midge is dependent on progressive buildup late in the year, an effective cultural recommendation became an important component in the management strategy. Early, uniform planting of grain sorghum, so that blooming occurred throughout the area during a relatively short period, made possible escape from this pest (25).

Relatively small acreages of grain sorghum are now planted late, but those that are may require insecticidal treatment to prevent loss. For these situations, insecticidal control decisions are based on economic threshold levels. It is recommended that fields be carefully inspected daily for adult midge, beginning when heads first start to bloom at the tip. Treatments should be applied when 25 to 30 percent of the heads have begun to bloom, and the mean number of midge adults per head exceed one (J. R. Cate, Jr., unpublished data). If adults are still active 3-5 days later, immediately apply a second treatment. Three applications at 3-day intervals may be justified if the yield potential is high and midge are abundant.

Another management tool was recently discovered in Texas that could have far-reaching implications in the management of sorghum pests--the discovery of sorghum from the conversion program that are resistant to the sorghum midge (13) (Figure 1). Resistant sorghums not only provide a an escape from midge damage but provide flexibility in time of planting. Sorghums can be planted later in the season, thus allowing for more efficient use of natural rainfall. Equally as significant is the fact that freedom to plant later in the season without fear of midge damage would permit sorghum to bloom and mature during the cooler, wetter part of the season. This is not only advantageous yield-wise but reduces irrigation requirements because of seasonal rainfall patterns.

Possibly even more significant is the fact that midge-resistant sorghums provide another approach to dealing with a serious threat to sorghum production, the Banks grass mite. The ability to plant grain sorghum later in the season allows maturation of sorghum during the cooler, wetter part of the season, which, characteristically, is not conducive to buildup of the mite. This pest increases in abundance more rapidly after the heading stage of sorghum and during periods of hot, dry climatic conditions.

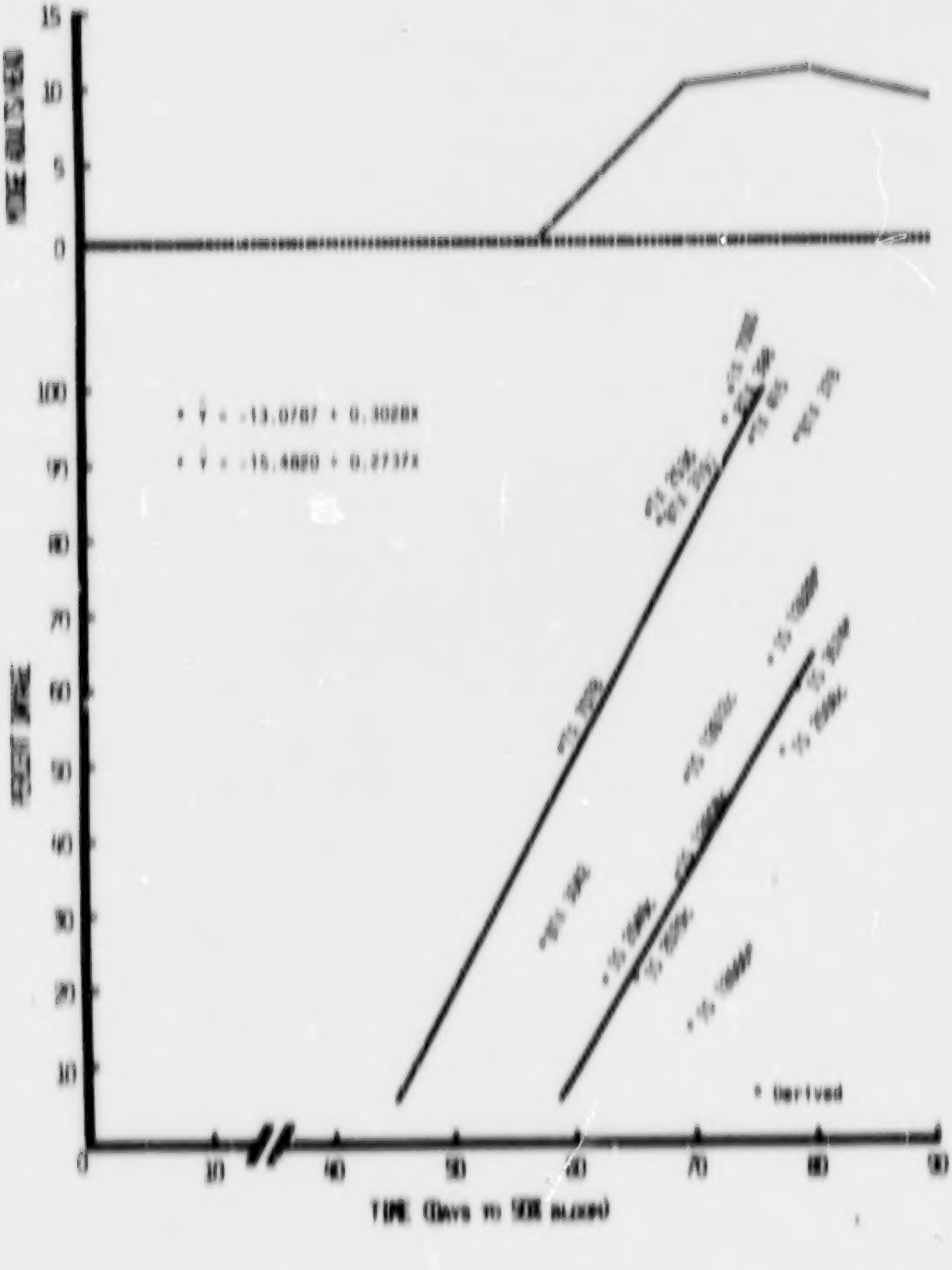

Figure 1. Damage ratings of sorghum midge resistant and susceptible sorghums in relation to population density and time.

Greenbug

The greenbug is also a key pest of sorghum. The first outbreak occurred in 1968 in almost all areas of the United States where sorghum is produced (2). This greenbug was identified as biotype "C" and differed in several aspects from the previous biotypes "A" and "B" which attacked small grains (10).

The greenbug damages grain sorghum by feeding on the plant leaves (1). It sucks sap from the leaves and injects a toxin. The combined effects from the sap loss and toxin injection cause severe leaf damage under heavy population attack. Extremely heavy infestations will kill most of the plant leaves.

The reproductive population of greenbugs on sorghum consists only of females that give birth to living offspring. A population may consist of both winged and wingless members (3).

A buildup of a damaging population on grain sorghum often follows this course:

1. Winged greenbugs fly from early spring hosts to small grain sorghum. The pattern of seasonal host infestation is grain sorghum to johnsongrass to wheat and then from wheat to johnsongrass to grain sorghum (Figure 2).
2. Reproduction begins immediately, with the population sometimes increasing at a rate of 20-fold per week with a seasonal weekly increase of about 6-fold.
3. If not controlled, the population will continue to increase until mid-July to early August; then it usually declines rapidly (Figure 3).

Beneficial parasites and predators become abundant as greenbug numbers increase and parasites are very effective in destroying the greenbug population. Abundance of natural enemies has shown the characteristic lag time of about 1-2 weeks, and natural aphid predators have not always held greenbug populations in check, but they do influence greenbug abundance (Figure 4). The major seasonal mortality factor in the greenbug population is parasitism (26). Certain abiotic components of the environment, especially rain and wind, can drastically reduce greenbug density early in the growing season. Thus, it is apparent that the greenbug is under the influence of natural control agents for a majority of the growing season. There is only about a 2-week period in which greenbug numbers may approach the economic injury level.

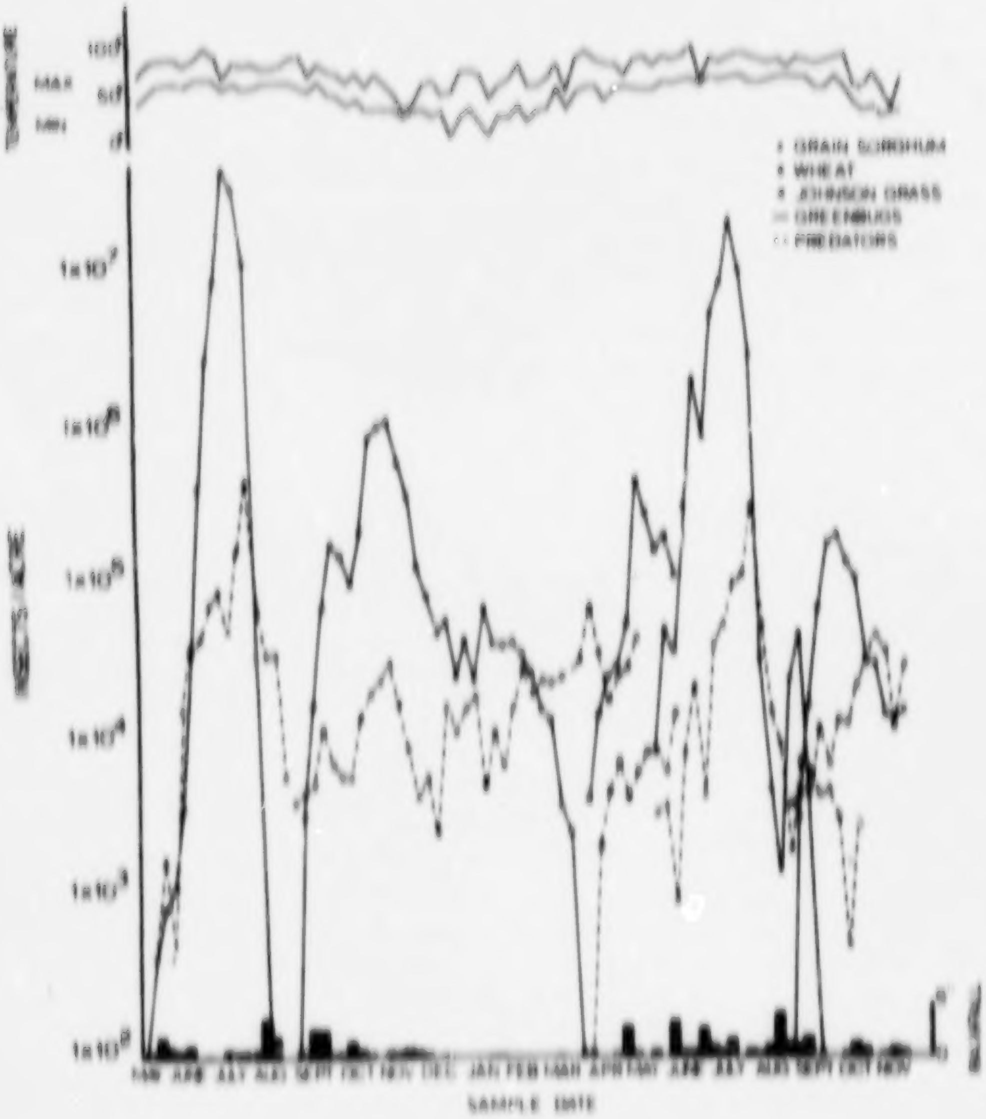

Figure 2. Seasonal population profile of the greenbug on the Texas High Plains.

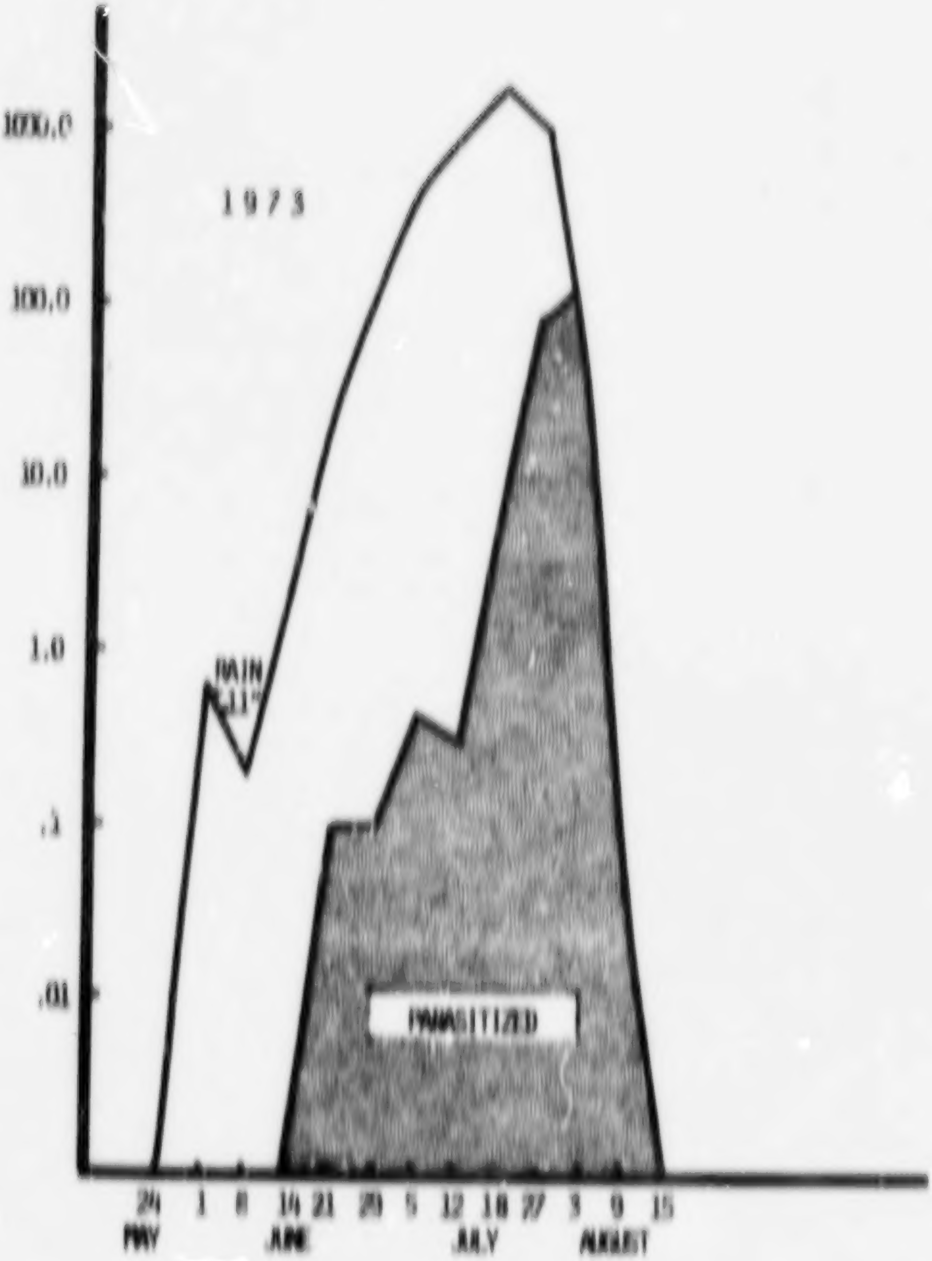

Figure 3. Seasonal abundance and parasitism of the greenbug in grain sorghum.

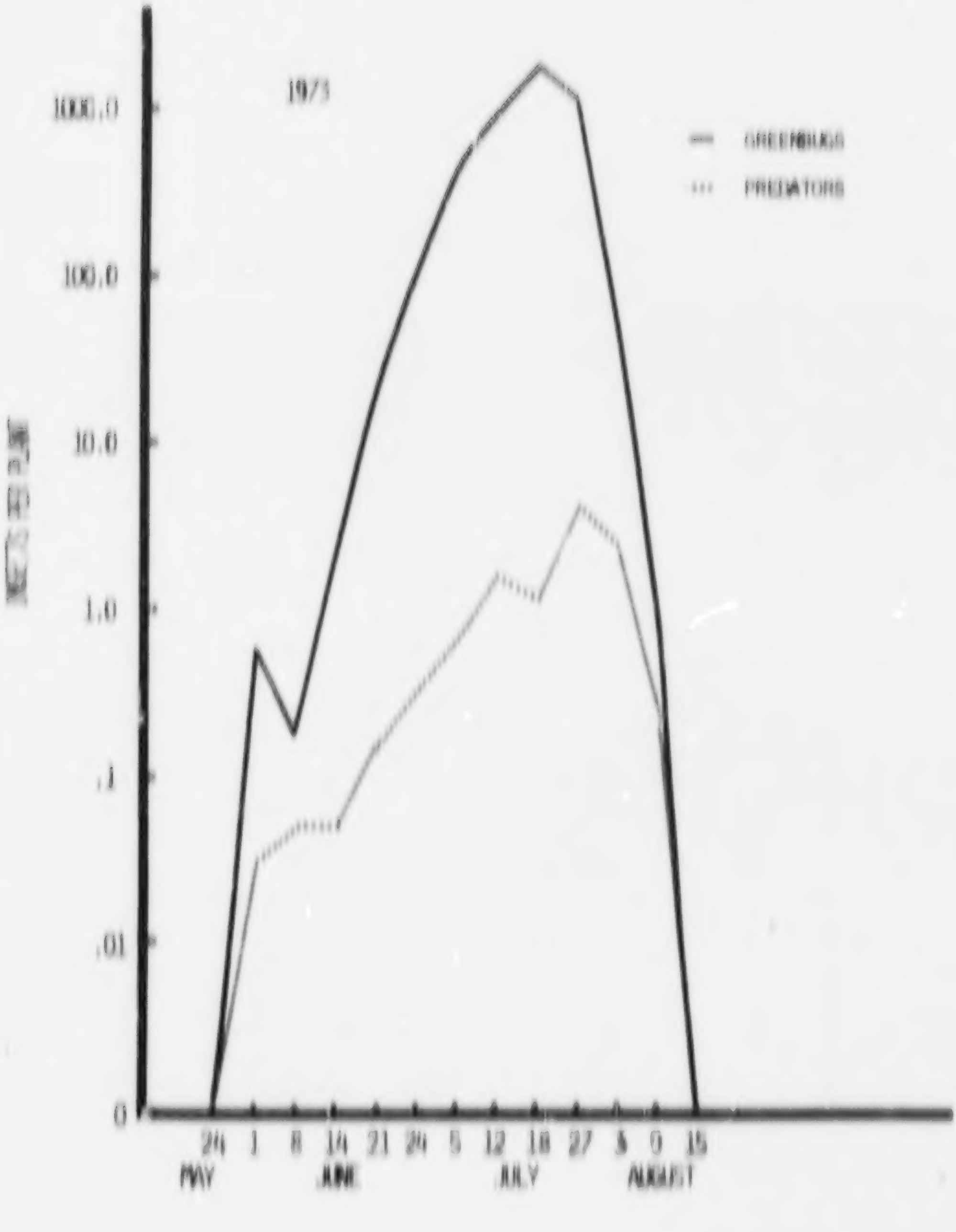

Figure 4. Seasonal abundance and predation of the greenbug in grain sorghum.

No integrated control strategy can function without an assessment of population densities of the key pest required to cause economic yield loss. Damage tolerance levels, primarily the economic injury level, must be determined so an economic threshold (the density at which artificial control measures should be implemented to prevent an increasing pest population from reaching the economic injury level) can be established. Data accumulated since 1971 have shown in general that greenbug numbers in excess of 1,300-1,500 per plant and leaf kill in excess of 3 per plant at about the bloom stage is required to cause economic yield loss in grain sorghum (17, 18).

Once an economic threshold was developed, a means of suppressing greenbug populations to prevent them from reaching the economic injury level was needed. Chemicals were necessary, but nonselective insecticides could eliminate the biotic factors holding other pests in check. Selectivity was achieved by rate manipulation. It was found that extremely low dosage rates (≤.1 pound active ingredient per acre) of several approved chemicals provided greenbug suppression yet spared most of the naturally occurring beneficial species (5, 15, 20). Treatments with selective insecticide rates have the effect of throwing the balance back in favor of the natural control by preserving natural enemies. Such selective treatments are applied when the aphid population reaches the economic threshold. When properly timed, only one insecticide application is required, and resurgence of the greenbug is prevented by the natural control afforded by parasites and predators.

Recent developments of insecticide resistance by the greenbug could greatly hamper the use of selective insecticide rates.

Results of laboratory tests conducted in Texas confirm field observations that the greenbug has developed resistance to several insecticides (Figure 5). Present results suggest that the level of resistance is about 30-, 10-, 3- and 2-fold for disulfoton, dimethoate, phorate and parathion, respectively, over a susceptible greenbug population (24). Greenbug populations in wheat also are resistant to several insecticides.

Another component of the integrated control program is greenbug-resistant sorghum hybrids (11, 12, 27). Sources of greenbug-resistant germ plasm were found soon after 1968, and releases of resistant breeding materials have been made to commercial seed companies by Texas Agricultural Experiment Station sorghum breeders. Hybrid sorghums resistant to the greenbug were available in limited supply in 1975, with much greater quantities available in 1976. Since the principle mechanism of resistance to the greenbug in these grain sorghums is tolerance (14, 22, 23), the economic injury level is raised with little or no disruption of the agroecosystem. This is because the greenbug can attain numbers sufficiently high on these varieties to maintain beneficial insect populations, and the end result will be that the pest and its natural enemies will come into balance, with pest numbers being kept below crop-damaging levels. Insecticidal control for greenbug then will not be required.

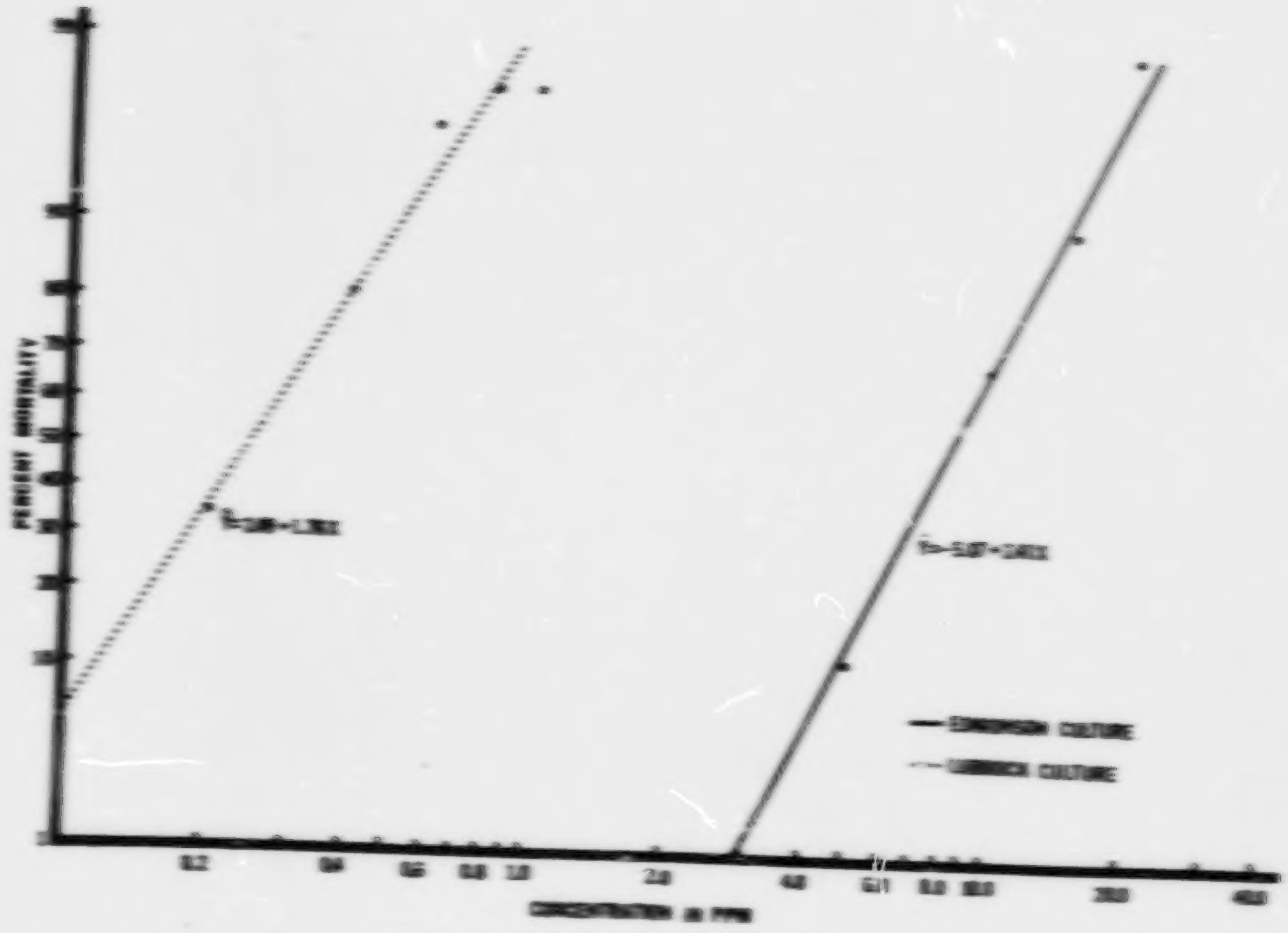

Figure 5. Dosage-mortality after 48 h of 2 populations of the greenbug treated with disulfoton.

In the High Plains of Texas, grain sorghum and cotton are the two major crops. Presently, insect pest problems in cotton on the High Plains are in direct contrast to that of the other major cotton-producing regions of the country. There are no serious problems with key pests such as boll weevils, and annual, widespread and damaging insect infestations in cotton have not occurred. As a result, insecticides have not been widely applied to cotton since other pests, such as bollworms, spider mites and aphids, are kept in check by their natural enemies. In the High Plains area, grain sorghum serves as the major source of natural enemies which later are active in cotton (Figure 6). Therefore, indiscriminate use of insecticides in grain sorghum may well result in increased insecticide usage in cotton because of the destruction of arthropod predators and parasites in grain sorghum before they disperse to cotton. Also, the drift of insecticide from sorghum to cotton can kill these beneficial insects, thus allowing the bollworm to escape natural control and to increase to damaging numbers.

Secondary Pests

Even though the greenbug is currently responsible for most of the insecticidal control being executed in sorghum in Texas (up to $14 million annually), the Banks grass mite has also spurred considerable use of insecticide.

This spider mite is first found feeding on the underside of the lower functional leaves along the midrib. The infested areas of the leaves are pale yellow initially and later take on a reddish color on the top side of the leaves. As mite numbers increase on the lower leaves, the infestation spreads upward through the plant. The underside of heavily infested leaves will have a dense deposit of fine webbing spun by the mites. In the final stages of infestation, the mites completely web up the sorghum heads.

Research-wise, knowledge of the spider mite complex in sorghum is limited. There are at least four species of the spider mites infesting grain sorghum in Texas (7). The Banks grass mite is the species most frequently encountered.

Spider mite outbreaks are closely correlated with reproductive maturity of the plant. Rapid population increases generally begin after heading. Infestations of mites appear to be separated temporarily and spatially from populations of effective natural enemies (7). Also, there is a positive correlation between mite density and hot, dry climatic conditions. In some areas the mite is extremely difficult to control with

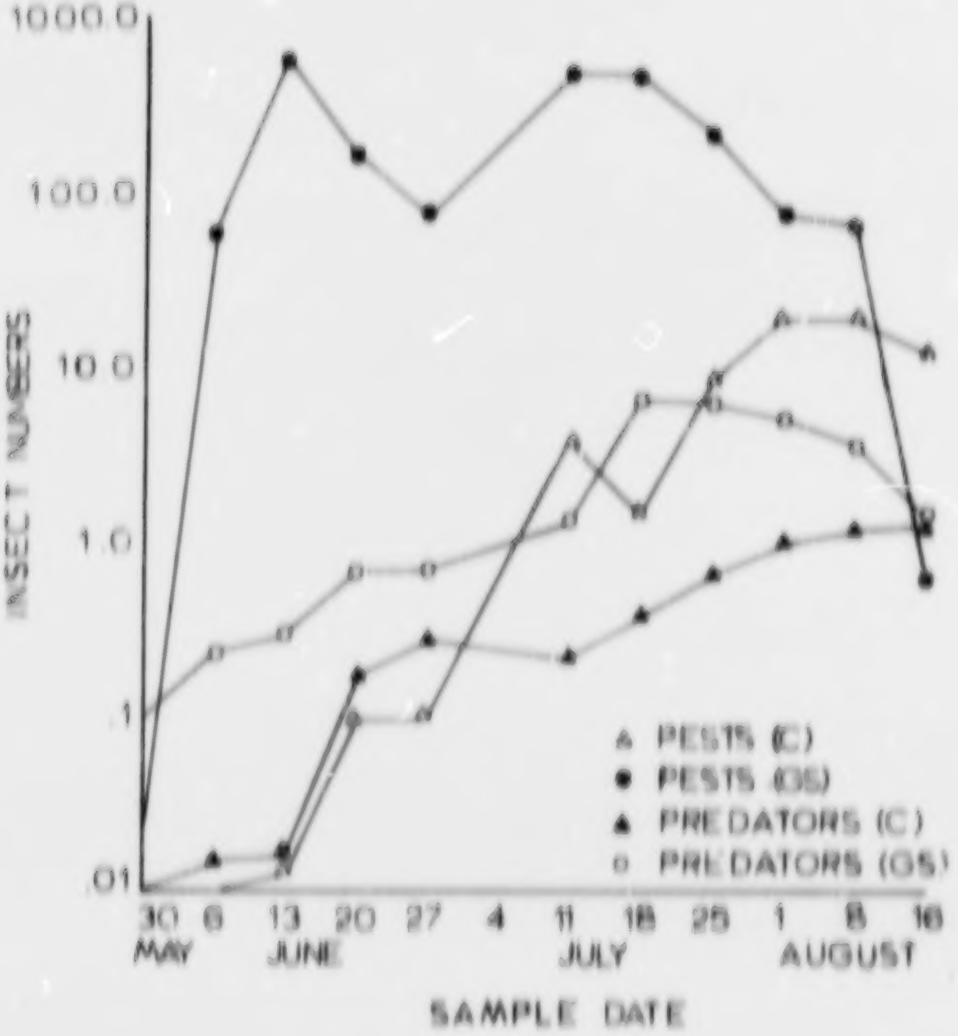

Figure 5. Predator and pest abundance in grain sorghum and cotton.

insecticides, especially in the Trans-Pecos area of Texas. There is also evidence of resistance in other localized areas of Texas. Some evidence exists to support the theory that some insecticidal treatments, especially parathion, applied for aphid control enhances the severity of the mite, a classic example of a secondary pest becoming important when a key pest is treated.

In general, the Banks grass mite is a serious potential threat; the species can be influenced by weather, plant maturity and previous insecticide treatment. Greatest opportunity for dealing with this pest lies in the area of host plant resistance. Screening trials for a period of 3 years of sorghums from the conversion program, especially some "non-senescing" types, look particularly promising.

Occasional Pests

Other insect pests attacking grain sorghum are categorized as occasional pests. If they are not considered in a total management scheme, their outbreak can cause difficulty and weaken the control system because of the uncertainty involved.

Corn Earworm and Fall Armyworm

Corn earworms and fall armyworms, two occasional pests, deposit eggs on the leaves or in the head of sorghum, and the newly hatched larvae begin to feed almost immediately. Feeding may occur within the whorl of young sorghum or in the head. Damage within the whorl appears later as rows of holes across the leaf. In the sorghum head, larvae consume the grains. Experimental results indicate that chemical control of corn earworm or fall armyworm is seldom justified economically. Cannibalism by corn earworm larvae is an important factor. Also, natural control by predators is often sufficient. Chemical control is recommended only when populations exceed a mean of two small larvae per head in the absence of natural predators. The use of "open-headed" sorghums has distinct advantages, and they are seldom damaged to the extent of "tight-headed" sorghums.

Sorghum Webworm

The sorghum webworm occurs primarily in the more humid eastern half of Texas. It frequently occurs in large numbers in grain sorghum heads, where it gnaws circular holes in the grains and feeds upon the starchy contents. In order to make judgment decisions for chemical control, heads should be inspected beginning in the bloom stage and continuing until hard dough. Control is suggested when heads are infested with a mean of five or more small larvae per head. Planting sorghum early often provides a means of escaping this pest.

White Grub

White grubs are the larval stage of May or June beetles. Damage to grain sorghum may occur in several different ways. The most obvious damage, and perhaps the most significant, is death of seedling plants from larvae feeding on the roots. Seed germination occurs, and a satisfactory stand is established. Within a short period, however, when plants are 4 to 6 inches tall, death of these seedlings begins to occur. In severely infested areas, stand loss can occur within 1 week to 10 days. One grub is able to destroy all plants within 1-2 feet of row. Plants which are not killed as seedlings are stunted severely and in many cases never produce seed. A third type of damage results from root pruning by larvae which overwintered plus those produced during the growing season. Plants which are able to produce seedheads in many cases do not have sufficient roots to prevent lodging. In some cases, lodging is enhanced by secondary stalk rot organisms.

Seasonal field biology data would indicate the possibility of delayed planting as a means to escape seedling damage (19). However, the crop remains susceptible to attack later in the season. These data have also revealed the fact that some individuals have a life cycle longer than 1 year. Light trap data have shown only one major peak in adult abundance and activity.

Damage assessment studies have shown that the economic injury level is two grubs per square foot, and the economic threshold has been set at one grub per square foot (16). Because of the nature of the grub infestations, a preplant broadcast incorporated application of insecticide is required for control when the economic threshold is exceeded.

False Chinch Bug

Infestations of a lygaeid bug in grain sorghum are sporadic, but they cause considerable concern to producers because of extremely high population levels. Populations of this false chinch bug are concentrated in small areas, and general infestations over an entire grain sorghum field are rare. Reproduction has not been observed on this host.

Damage results when bugs suck juices from the developing seed. Commonly, the damaged seed are infected with a fungus (*Alternaria* sp.) which causes the seed to be black in color, resulting in further deterioration of quality. Damaged seed rarely develop fully, are considerably smaller, softer and lighter in weight than the undamaged seed and are subject to loss in harvesting. This false chinch bug also feeds in clusters on the leaves of sorghum; however, little leaf damage results.

Damage assessment studies by confining different populations in cages on sorghum heads have shown in general that for each additional 10 false chinch bugs per head, there was a 1-percent increase in damaged seed (21). Actual yield loss, however, was evident only when 200 bugs per head damaged 23 percent of the seed (Figure 7). Increase in weight of undamaged seed apparently compensated for yield loss to a point. Only when percentage of damaged seed was greater than percentage increase in seed weight was there evidence of reduced yields. The point of equal compensatory effect occurred at 14-percent damaged seed or approximately 140 bugs per head. Spot treatment with insecticides may be required to prevent yield loss.

Stalk Borers

Stalk borers, namely the southwestern corn borer, sugarcane borer and sugarcane rootstock weevil, may cause damage from extensive tunneling and girdling of the stalk which often results in stalk lodging. Only light infestations have in general been reported in grain sorghum. Although efforts at chemical control of stalk borers in grain sorghum have generally given sporadic results, insecticides may be justified in ratoon sorghum.

Various cultural control practices appear to afford the most effective means of controlling these pest. Area-wide stalk destruction through practices such as double disking and deep breaking destroy the plant crown that provides habitat for overwintering larvae. Research and observational data indicate that early plantings may escape infestation and are less susceptible to plant lodging. A reasonable plant population to insure large healthy stalks, along with proper fertilization and adequate irrigation, help prevent lodging of borer-infested stalks. Crop rotation, use of early maturing varieties and early harvest with equipment designed to pick up lodged stalks aid in reducing yield losses.

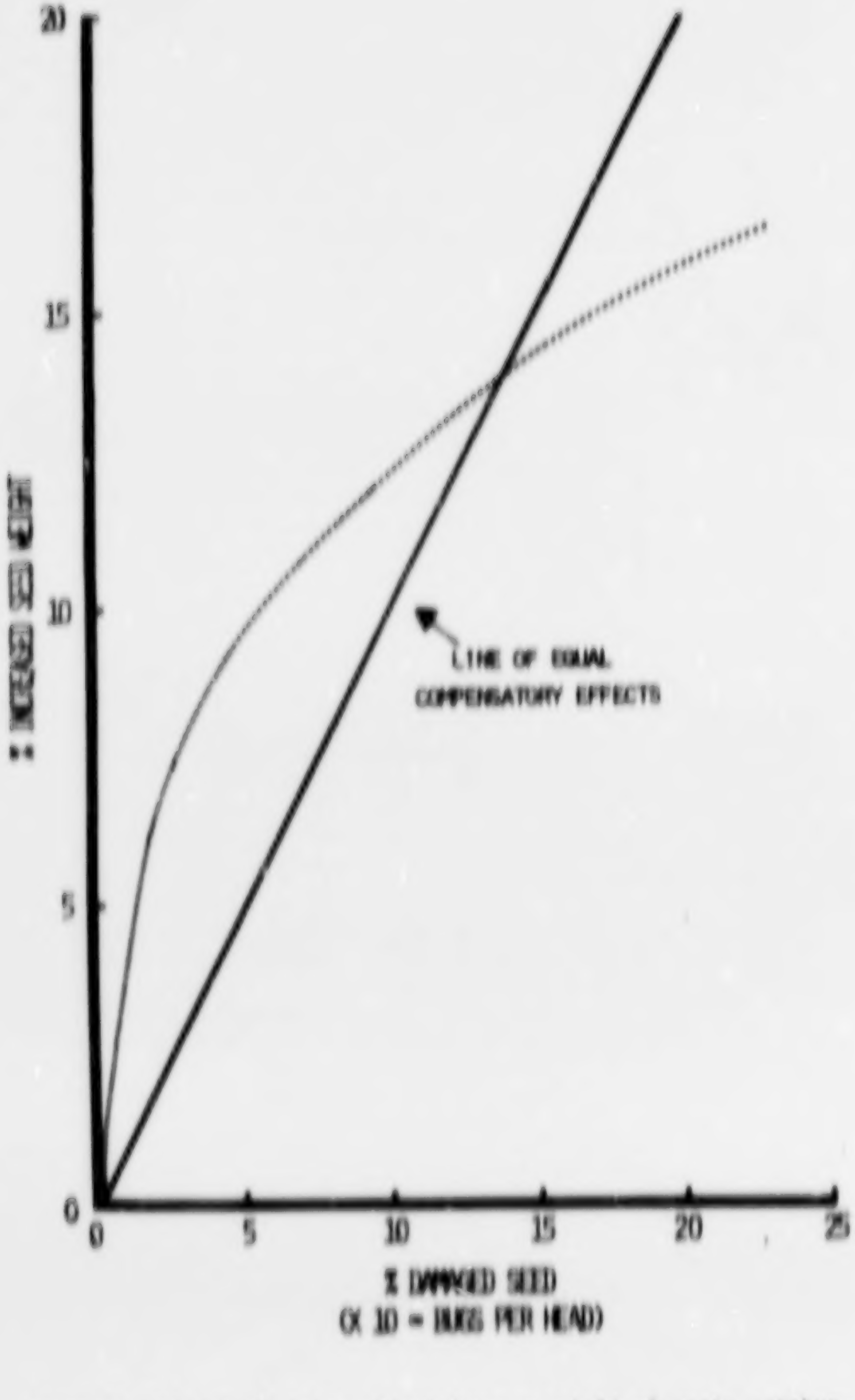

Figure 7. Effect of false chinch bugs on yield of grain sorghum.

Wireworms

The severity of wireworms in sorghum has been masked because of the effectiveness of extremely low rates of chlorinated hydrocarbon insecticides applied as seed protectants. These pests may become an important consideration as USDA decisions ban certain insecticides.

Preliminary research results have shown that possible replacements for dieldrin as a seed treatment include carbofuran and Dasanit®. Failure to obtain registration of alternate seed treatments for wireworm control may lead to the use of much higher insecticide dosage rates applied as in-furrow applications.

Grain-baited traps can be used to determine wireworm population levels prior to planting. Based on damage assessment studies, (Teetes, unpublished data) populations of wireworms exceeding 1 per linear row foot is required to reduce plant stands sufficiently to reduce yields.

Although it may be necessary to research a pest or a crop independently at times, it is mandatory that problems as a whole be considered. There must be an integration of biological, ecological, cultural and chemical data into a sound scheme for insect population management. Ecosystems are not always naturally balanced. It is important to insure that the control techniques implemented do not, in fact, cause an even greater imbalance.

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IMPLEMENTATION OF AN INTEGRATED PEST MANAGEMENT PROGRAM IN SORGHUM

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Implementation of successful pest management programs are dependent upon several factors: need for such a program, a research base to provide solutions to these needs, impetus to initiate a program, and personnel to make the program function. These requirements are common to all programs, without concern for the crop or pests involved. This paper deals primarily with insect pests in sorghum, but the principles would apply equally to plant or disease pests. After covering the points in implementation of such a program, it will be shown how the Texas Grain Sorghum Pest Management Program met each point in its formative phase.

The Need for Integrated Management

For program goals to be achieved, the program must meet recognized needs of the producers to whom it is directed. In programs aimed at insect pests, these problems may include one or more insect species, pesticide misuse, economically unsound pest control techniques, health or environmental hazards from pesticide use and potential problems of insecticide resistance or secondary pest outbreak. In situations where an insect pest or pests are present and chemical control is habitually used, some or all of the other problems may be present. Thus, some aims of a pest management program may involve better management of insect control tools as well as managing pests. Lack of producer recognition of problems and the need for solutions is a major limiting factor in initiation of a pest management program. Initially, a pest management program may have to make producers aware of the present and potential problems associated with their specific situation.

Problems alone cannot justify a pest management program - solutions to these problems are also essential. Until solutions to the problems are provided by research, pest management programs have nothing to offer. While all answers are not required before program initiation, information to improve the current situation must be available. The more complete the research base, the more effectively the program can function. It should be realized that even successful programs can be improved or modified by new research information. With the constant change in cropping patterns and insect response to these changes, pest management programs are dependent upon continuing research information to keep abreast of the situation.

Problem solutions and pest management concepts to be introduced by the pest management program must be compatible to the cultural system into which it is to be incorporated. While some rather drastic changes can be realized with time, initial changes will be small and accepted only if no major cultural changes are required. Pest control decisions are usually made on an emergency basis, while many other cropping decisions are well thought-out and planned. Potential damage from insects is great, and if current control procedures protect the crop, producers are usually content with these practices. Changes in this procedure will take time.

Many producers fail to recognize that almost everything which affects the crop also affects the insects that attack the crop. In many cases small changes in cultural practices can greatly alter overall insect problems.

Impetus for Program Initiation

Impetus to implement a pest management program or even adopt new control procedures, developed by research, will not come automatically. If stop-gap solutions to insect problems are available they will usually be accepted and utilized. Impetus for implementation of scientifically sound control programs must come from within the sorghum industry. When the scope of the problem is fully understood and the research data to alleviate these problems are recognized and accepted by industry leaders, program implementation may follow. When producer organizations and key producers recognize the advantages offered by pest management concepts in alleviating current problems and in preventing or postponing the onset of potential problems, initial farm trails of these concepts will be undertaken. As initial endeavors prove successful, these groups will provide the impetus to implement a pest management program on a larger scale.

The recognition of far-reaching problems that can disrupt an entire farm industry is one situation that can greatly speed up this implementation. Secondary pest outbreaks and development of insecticide resistance are two problems that can affect a crop or commodity over a wide area and can even threaten the continued production of the crop or commodity. Thus we can see that practices undertaken by a few producers may affect all producers.

Development of Program

With the needed impetus to move toward implementation of a pest management program, development of the program is the next step. Program development relates to deciding upon type of program to use, location of the program and size of the program based on available manpower. Input from all sources is needed. Local and regional producer groups, commodity organizations, research scientists, federal and state agriculture departments and the Extension Service are groups that would have some input into program development.

While the specific type of program may vary, there are several factors that will be required of any type. All integrated pest management decisions must be based on actual field information, so field scouts are necessary and, in most cases, a professional entomologist is necessary to aid in interpretation of this field information. From this point the arrangements for program type is quite flexible.

Site selection plays a major part in the program development and may precede or follow the selection of the program type. Producers who will be involved may have some preference as to the type of program they want and can play a major role in program development. To realize the maximum benefit, a demonstration-type program area should meet certain criteria: (1) the area selected must have the problem to which the program is addressed; (2) the cropping patterns of the selected area must be representative of those of the entire area and (3) the farming and cultural practices must be representative of the entire area. If these criteria are met, the area can very closely parallel other areas, and the results can be expected to be duplicated. Producers outside the program area will recognize that their own situation is similar to that of the program area and will be encouraged to follow the program procedures.

While there are many facets that go into determining how a pest management program will operate, the acquisition of personnel is the most critical. Without an adequate number of trained or trainable personnel the program cannot function. Decisions as to type and scope of the program must be based on this consideration.

Sample sizes, sampling procedures and other factors that determine the acreage one scout or scout team can adequately monitor and still provide accurate information must be provided by research information. This per-scout acreage and the number of scouts available will determine the total possible size of the program. With this information, the decision to set up a block-type program or a voluntary assignment program can be made. A "block" program would be one which involved all of the sorghum in a small area, while a voluntary assignment program would have larger boundaries with only part of the acreage assigned to the program by producers interested in changing their pest control techniques. A block program usually can be obtained only with a great deal of persuasion toward acceptance of the concepts introduced. Some producers will allow field scouts to monitor their fields, but when the time comes to act on the results of the field monitoring, they will use the same decisionmaking concepts and control techniques they have always used. Full adherence to the pest management concepts can more easily be obtained through a voluntary assignment program, because the producers must have some interest in the study to assign their acreage to the program. This is especially true if producer money is involved. While a block program affords greater results, in that the concepts are applied to all acreage of the crop in the area, changes may be more easily brought about by voluntary assignment.

Success of pest management programs are dependent upon personnel upon whom producers can rely to meet the entomological problems without endangering valuable crops. The professional entomologist especially must have the confidence of the producers and be readily available to the producer at all times.

Personnel training is a very important aspect of program operation. While some adequately trained individual may be found, it must be expected that extensive training will be required to reach the level of competence required. Provisions for this training must be made to provide adequate instruction for all personnel, regardless of background.

Distribution of information obtained by field scouts is another important part of the operation of a pest management program. Before any insect control decisions can be made, accurate field information must be available. Written records that clearly and precisely indicate population levels are a must. Techniques that allow for rapid verbal relay of information are also necessary.

Delineation of the decisionmaking processes must be made before field operations of a pest management program begin. Final control decisions will rest with the producer, with the professional entomologist providing interpretation of field data. Much of the information as to economic threshold for insect pests, beneficial pest insect interaction and insecticide and rate recommendations can be provided in writing, but the entomologist must be readily available to provide answers to specific questions.

Evaluation plans need to be arranged before program initiation. Program evaluation is required to determine if goals are being reached and desired changes being made. Producers in the program must be satisfied that the changes they made did not adversely affect their crop production. Distribution of the program results will go a long way in affecting insect management techniques by other producers.

Texas Grain Sorghum Pest Management Program

Examination of the Texas Grain Sorghum Pest Management Program can be used to illustrate the steps numerated above.

Except for the sorghum midge, *Contarina sorghicola* (Coquillet), grain sorghum on the High Plains of Texas had no major insect pest before 1968. The midge problem was circumvented by early, uniform planting of sorghum to facilitate blooming before damaging midge populations were built up. In 1968, Biotype C of the greenbug, *Schizaphis graminum* (Rondani), emerged as a pest of sorghum throughout the Great Plains and has become a key pest in the High Plains of Texas.

Producers and aerial applicators soon developed insecticidal control techniques that prevented crop losses from the greenbug. The techniques developed and utilized by most producers were automatic or preventive applications of systemic insecticides. These applications were normally applied without regard to population levels of *S. graminum* and were applied as a matter of course.

Beginning in 1968, research entomologists throughout the area conducted research on *S. graminum* to provide producers a scientifically sound pest management concept. Economic threshold data, seasonal history, natural control factors and selective insecticide rates were major areas of emphasis.

By 1971 enough information was available to enable producers to utilize integrated pest management techniques in combating the greenbug. Using economic thresholds established for *S. graminum*, an Extension entomologist estimated that only 10-15 percent of the acreage actually required treatment to prevent economic loss in 1971. Surveys also indicated that producers continued to use insecticide rates that often were 10-fold above selective rates shown effective in controlling the greenbug while sparing most of the beneficial insects present.

Not only are preventive applications of pesticides economically unsound, they pose other potential problems. Secondary pest outbreaks and insecticide resistance in target and nontarget pests are examples of these potential problems. Damaging infestations of the Banks grass mite, *Oligonychus pratensis* (Banks), have occurred periodically in grain sorghum since 1968 and are conjectured to be the result of the automatic control program which removes the mite's natural enemies. Pesticide resistance developed in isolated populations of *O. pratensis* by 1970.

It can be seen from these examples that the High Plains of Texas had a problem to which an integrated pest management program could be directed. A key pest, coupled with an economically and scientifically unsound control program, and the potential problems of secondary pests and insecticide resistance together created a difficult job for area entomologists.

A research base to solve the current problems and to greatly alleviate the threat of the potential problem was available by 1971. Lacking was the impetus to initiate a program to affect the adoption of pest management concepts. Presentation of research results, indicating that the concepts put forth would provide protection to sorghum yields, began to make industry leaders aware of possible changes. When these same leaders recognized that the potential problems associated with the current greenbug control techniques threatened the very existance of the sorghum industry on the High Plains, impetus to implement a pest management program increased.

In 1971 and 1972 research and extension entomologist met with grain sorghum industry leaders to draw up plans to implement some type of program to make producers aware of the integrated pest management concepts developed. The Texas Grain Sorghum Producers Board, an organization of grain sorghum producers in a 29-county area, and key sorghum producers worked closely with entomologists in obtaining federal and producer support for a large-scale demonstration of these concepts.

Program site selection again was a joint effort among these groups. The Edmonson community in Hale County was selected as the program area. This area of high-yield potential farm land met the three requirements set forth previously. All of the problems associated with *S. graminum* and the resultant chemical applications were present. Producers in this area practiced a sorghum, cotton and wheat cropping pattern that was representative of the entire High Plains. They also used farming and cultural practices consistent with all producers in the area.

From the beginning it was agreed that the Texas Grain Sorghum Pest Management Program would be a large scale demonstration with voluntary assignment of acreage. It was the belief that producers would be more attentive to recommendations and have more interest in the program if producer money was required. Also, if the program was to function after the initially funded 3-year period, producer money would have to support the program.

A county Extension entomologist was hired to direct the program on a full time basis. He was to live in Hale County, be in contact with the producers throughout the year and hire and train field scouts. Entomology students at Texas Tech University at Lubbock provided a source of some partially trained field scouts.

Research and Extension entomologists with field experience with *S. graminum* sample techniques worked out samples sizes and data collection techniques. For 1973, the first year of the program, it was determined that enough scouts could be hired, trained and supervised to scout about 16,000 acres. With voluntary assignment a program area of about 100 square miles would be required to obtain this acreage.

Within the Texas program, field scouts gather field information and provide the producer and professional entomologist this information on the day of inspection. Producers have been provided published information upon which to make control decisions based on the scout reports. The county entomologist is available 24 hours a day by phone to answer questions and assist producers in making these control decisions. Decisionmaking remains a responsibility of the producer.

Evaluation of the Texas Grain Sorghum Pest Management Program was planned for before program initiation and has been carried out yearly. Information gathered for evaluation purposes includes insecticide use (type, amount, number of applications and total insecticide applied), cost of insect control, grain yield, and producer satisfaction with the program.

The program has increased in acreage scouted each of the 2 subsequent years of operation, and retention of participating producers has been high. Changes in crops grown and insect situations prompted producers to request expansion of the program to include corn and sunflowers in 1975. These crops have key pests associated with them, and the potential problems of possible secondary pest outbreaks and insecticide resistance in these pests are present.

Public release of the information gained in evaluating the pest management program has made other producers aware of changes that can be made in insect control practices to prevent economic loss and to provide a scientifically sound approach to present and future problems. This demonstration of scientifically and economically sound pest management concepts has increased acceptance of these concepts by other producers and has brought about an increased interest in their use in other crops.

Summary

Implementation of integrated pest management programs requires that several factors be present and a great deal of planning and supervision be carried out. Recognized problems to which answers are available is one element that must be present for any proposed program to succeed. Some group, usually the commodity industry, must provide the impetus to implement such a program. Planning must provide for selection of a site, personnel, operations and evaluation before attempts to initiate the program.

If these elements are present and can be met successfully, integrated pest management programs can provide solutions to many problems facing farmers of today.

THE DEVELOPMENT OF PEST-RESISTANT SORGHUM

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Increase in the production of a crop, especially when the crop is grown in large monocultures, inevitably results in increasing pest problems. The experience of sorghum producers during the past 15 years has shown that sorghum is no exception to the rule. The sorghum midge (*Contarinia sorghicola* Coquillett) has been a pest of sorghum in the South Texas area for over 50 years but did its first significant damage in the High Plains in 1961 (1). Two additional pests, the Banks grass mite (*Oligonychus* sp.) and the greenbug (*Schizaphis graminum* Rondani), have attained economic importance since 1967.

An intensified program to identify and improve sorghum resistance to arthropod pests was begun by the Texas Agricultural Experiment Station in 1969. At the beginning of this effort certain questions were posed that required answers if the goal of insect-resistant, agronomically superior sorghum was to be obtained:

1. Does resistance to the pest under consideration exist?
2. If resistance is obtained, what effect will it have on the quality of the final product?
3. If resistance is obtained, will it be necessary to accept a lower yield potential when the pest is not present?
4. Are the plant characters associated with resistance those which would aid the breeder in selection if the selection must be made when the pest is not present?

As will be evident in this paper, answers have been obtained to only a portion of these questions, but results to date are adequate to recommend an expanded effort in breeding for host plant resistance to arthropod pests.

Greenbug

Resistance to greenbugs in sorghum has been reported in the seedling stage (3,5,6,13,14,15,16,18) and the adult plant stage (4,7,9,17). The inheritance of greenbug resistance in lines that have been studied is dominant or incompletely dominant (3,6,9,18).

Resistant cultivars first identified were not suitable for commercial grain production, and considerable breeding work has been done to incorporate this resistance into commercially acceptable lines. Releases of agronomically improved resistant lines have been made by Agricultural Experiment Station personnel in Kansas, Oklahoma and Texas, and commercial companies have made excellent progress in improving resistant types.

Since it has been established that greenbug resistance is not complexly inherited and can be retained through several backcrosses, the primary need is an effective evaluation technique to identify resistant material in segregating populations.

Seedling Evaluation

The technique described by Wood (21) for evaluating small grains has been modified for use on sorghum. This technique consists of culturing greenbug biotype C on a susceptible sorghum hybrid grown in 1-gallon cans. From 30 to 50 seeds are planted per can in soil and covered with sand to a depth of 1 inch. Before emergence, plants are covered with a cage inserted into the sand in each can to protect them from premature greenbug infestation and to prevent infestation by parasitic wasps. Cages are constructed of clear vinyl plastic 0.015 inch thick, 13 inches high and 5.5 inches in diameter. Ventilation is aided by cutting holes 2.5 inches in diameter in two sides of the cage. The ventilation holes and the cage top are covered with fine mesh nylon cloth. After the culture plants have reached a height of 6 to 8 inches, each can is infested with about 200 greenbugs. After about 2 weeks these cultures are ready to use.

Breeding lines to be evaluated for resistance are planted in galvanized metal flats 14 x 20 x 3.75 inches. This flat accomodates 10 entries in rows 14 inches long. A resistant and susceptible check is planted in each flat. Approximately 20 seed of each entry is planted per row. These plants are infested when 3 inches high, from the culture plants by brushing approximately 1,500 greenbugs on each flat.

Rating for resistance begins when the susceptible variety is near death. A 1-to-9 rating system is used, where 1 equals no damage and 9 equals dead plants. Rows segregating for resistance are recorded, and a rating is given on the most resistant plant in the row. This procedure permits evaluation to begin on seed from plants selected from F_2 populations.

Adult Plant Evaluation

Resistance of most lines are easily detected in the field, if natural greenbug populations are at an adequate level. Natural populations averaging over 200 per plant are required to obtain reliable data on adult plants. The rating system given in Table 1 is useful in evaluating nursery material. When susceptible checks are rated as 6, resistant selections should have a rating no higher than 3. When susceptible checks are rated 3 or 4, resistant selections should have a rating no higher than 1.

Evaluations should be made when greenbugs are present. If too much time elapses between maximum greenbug infestation and the time evaluations are made, it is difficult to distinguish natural leaf death of the lower leaves and death caused by greenbug feeding.

Because of the low number of greenbugs occurring in the late-planted sorghum at Lubbock, a technique has been developed to artificially infest selected adult plants in the field. Materials needed in this procedure are clip-on cages described by Cate (2) and a small artist paint brush. The cages are a clip-on type, constructed of 1-inch-square plastic boxes. Screen-covered holes, 3/4 inch in diameter in opposite sides of the boxes allow ventilation within the cages. Five adult greenbugs are transferred from culture cans into each cage with a small artist brush. Two cages are attached to a leaf of each plant to be evaluated. The third leaf from the top of the plant is normally used. Cages are inspected the day following attachment to the leaves to insure that the five greenbugs are alive and feeding on the plant. Additional greenbugs are added as needed to bring the total to five. Resistant and susceptible checks are included in the test.

Snap cages can be used at any time, even on mature plants in the fall. This provides flexibility to the evaluation program and permits the breeder to determine when evaluations will be made.

Ratings of the leaf area under the cages begin about 1 week after infestation and are taken every 2 days if the greenbugs are reproducing well on the susceptible check. Plants that have more than 50 percent live leaf area under the cage on the same date that the susceptible check has more than 80 percent dead leaf area under the cage are considered to be resistant.

Using the techniques outlined above, two pollinator lines, TAM 2567 and TAM 2568, were developed. These lines were released in 1974 and were available in large quantities for use in 1975 hybrid production. These lines and their hybrids have been utilized to evaluate the effectiveness of homozygous, resistant and heterozygous, resistant plants.

Table 1. Proposed rating scheme for rating resistance of sorghum to greenbugs

Score	Description of damage*
1	No red spotting on leaves
2	Red spotting on leaves
3	Portion of a leaf killed by greenbugs
4	One entire leaf killed by greenbugs
5	Two entire leaves killed by greenbugs
6	Four entire leaves killed by greenbugs
7	Six entire leaves killed by greenbugs
8	Eight entire leaves killed by greenbugs
9	Plant killed by greenbugs

*Data may be taken at any plant growth stage when greenbugs are present. It is suggested that estimates of greenbug numbers be taken if possible.

Table 2. Damage assessments of greenbugs of homozygous resistant and heterozygous resistant, mature plants

Line or hybrid		Percent damage under cage*	Number of greenbugs
TAM 2567	(R)	3	94
A Tx 399 X TAM 2567	(R)	7	67
TAM 2568	(R)	4	110
A Tx 399 X TAM 2568	(R)	1	40
Tx 2536	(S)	77	118
A Tx 399 X Tx 2536	(S)	65	102

*Percent damage in 1-inch square area in which the greenbugs were confined by cages. Mean of six cages per entry.

Utilizing the snap cage technique on mature plants in the field, five adult greenbugs were caged on six plants of each entry (Table 2). There was little difference in damage among the resistant lines and their F_1 hybrids with the susceptible female 20 days after the cages were attached. However, greenbug numbers were lower on the hybrids than on their parents.

A comparison of homozygous resistant, heterozygous resistant and homozygous susceptible hybrids was conducted on seedlings (Table 3). Seedlings were infested when about 3 cm high and rated for the percentage of plant death at 5-day intervals. The homozygous resistant hybrid showed a slight advantage over the heterozygous hybrid after 10 days and a significant advantage after 15 days.

Tests containing resistant and susceptible hybrids were planted by several commercial companies in 1974. Yield data from a portion of these tests is presented in Table 4. Grain yields of the resistant hybrid greatly exceeded those of the susceptible hybrid in the presence of large greenbug numbers but only slightly exceeded yields of the susceptible hybrid when economic injury levels of the insect were not attained on susceptible varieties.

Data from these studies indicate that homozygous, resistant hybrids exhibit superior resistance over heterozygous, resistant hybrids in the seedling stage. The caged test on adult plants showed little difference between F_1 hybrids and resistant parents when the test was terminated. If it had been continued, a difference may have developed. Heterozygous, resistant hybrids probably will rarely require insecticide application under conditions experienced on the Texas High Plains since 1968.

Work continues to develop female lines for use in hybrids, but heterozygous, resistant hybrids should contribute greatly to the control of this insect.

The type of resistance present in TAM 2567 and TAM 2568 has not been studied critically. Field and greenhouse observations indicate that tolerance is by far the main component of resistance in these lines, although low levels of nonpreference or antibiosis cannot be ruled out. If antibiosis is nonexistent or at low levels on these lines, their use should not result in a rapid change of greenbug populations to types that could damage this source of resistance.

Resistance to disulfoton in populations of greenbugs was suspected following failure to obtain adequate control in grain sorghum grown in the Texas High Plains in 1974. Teetes (personal communication, 1974) reports that laboratory tests confirmed the findings of resistance to disulfoton and demonstrated a decrease in susceptibility of about 30-fold. If these populations increase their area of infestation, the use of host plant resistance to greenbugs may become a necessity in the near future.

Table 3. Greenbug damage to seedlings of sorghum hybrids

Hybrid	Days after infestation		
	10	15	20
	Percent plant death		
Resistant X Resistant	20	26	76
Resistant X Susceptible	34	70	95
Susceptible X Susceptible	100	100	100

Table 4. Effect of greenbug resistance on grain yield of resistant and susceptible hybrids, 1974

Hybrid		Grain yield, lb./acre	
		Control needed[1]	Control not needed[2]
A Tx 399 X Tx 2536	(S)	3500	5500
A Tx 399 X TAM 2567	(R)	5200	5800

[1] One test where susceptible entries were severely damaged by greenbugs.

[2] Mean of five tests where greenbugs did not reach economic injury levels on susceptible hybrids.

Midge

The sorghum midge is a pest of sorghum in almost all regions of the world where the crop is grown. Varieties resistant to the insect have been reported from several countries (8,10,11,12,19,20).

The sorghum midge adult is a small gnat-like fly, usually orange in color, that lays eggs in the florets of blooming sorghum. Larvae feed on the developing seed, preventing its full development. The plant is subject to damage from this insect only during its blooming stage. When evaluating sorghums for midge resistance, one must be sure that the lines bloomed at near the same time or that near-equal populations of midge were in the fields at the time the lines were blooming.

Since 1970, we have eliminated or greatly reduced insecticide application for midge control in our nurseries at Lubbock. The absence of midge control by insecticides provides the opportunity to select lines that have resistance. Using this approach, lines are identified for entry in midge evaluation tests. Converted and partially converted exotic lines from the sorghum conversion program and their progeny from hybridization with elite Texas material have been evaluated since 1971.

In order to provide a uniform infestation of midge over the test area, "spreader rows" are planted throughout the nursery with not over 50 feet between rows. These rows consist of a mixture of hybrids classed as early, medium and late in the location that the test or nursery will be grown.

The use of a large number of susceptible varieties as checks is required. Check varieties overlap in their maturity and include the earliest and latest varieties adapted to the area. This is especially important in areas that have a large fluctuation in midge numbers throughout the blooming period. At Lubbock, the midge population generally reaches damaging levels by mid-August and stays high until frost. However, in other areas, populations may be large one week and very small the next.

Of the lines tested, those that have shown the highest level of midge resistance are presented in Table 5. Only one line, IS 1309C is a nonrestorer. The lines with the highest level of resistance, TAM 2566 and IS 12666C, have a brown pericarp with a pigmented testa, but other resistant lines, such as IS 2579C and IS 2549C, have a white or translucent pericarp with no testa. The most obvious morphological difference between the resistant and susceptible types we have tested is their small glumes. All the lines identified in our studies with high levels of resistance are Caudatum types.

Table 5. Midge damage rating of selected sorghum lines, 1973 and 1974

Line	SC No.	Group name	Midge damage, score[1]		Days to bloom	
			1973	1974	1973	1974
IS 2501C	52	Nigricans-Feterita	1.8	2.6	63	60
IS 12608C	108	Zerazera	3.8	4.8	65	65
IS 12612C	112	Zerazera	3.4	6.3	65	63
IS 2816C	120	Zerazera	3.9	6.1	64	63
TAM 2566	175-9	Zerazera	1.8	3.6	64	67
IS 12666C	175	Zerazera	1.2	4.2	67	65
IS 2549C	228	Zerazera	3.2	3.1	59	60
IS 7007C	268	Caudatum-Nigricans	4.0	8.4	63	57
IS 1309C	322	Nigricans	3.2	4.7	70	66
IS 2508C	414	Caudatum-Kafir	4.3	5.8	70	63
IS 2579C	423	Zerazera	2.1	4.6	69	62
IS 8100C	424	Caudatum-Nigricans	3.4	6.2	57	60
TAM 428		Zerazera	-	8.0	-	67
SC1RL-MR-1[2]			4.5	6.7	66	63
Tx 2536[3]			8.2	9.7	67	64
Tx 7000[3]			8.7	10.0	69	66
B Tx 378[3]			7.8	9.1	69	66
Tx 7078[3]			6.9	9.7	63	62
B Tx 3042[3]			6.2	9.6	64	57
B Tx 3197[3]			7.6	9.6	67	63
Tx 415[3]			8.6	9.5	70	67

[1] The 1974 mean score of six 4-replication tests at 4 locations, Georgia, Mississippi and Lubbock and Beeville, Texas. 1973 mean score of three 4-replication tests at Experiment, Georgia and Beeville, Texas. 1 = <10% seed loss, 2 = >10 <20, 3 = >20 <30, 4 = >30 <40, 5 = >40 <50, 6 = >50 <60, 7 = >60 <70, 8 = >70 <80, 9 = >80.

[2] Resistant check.

[3] Susceptible check.

The number of midge present on blooming sorghum was recorded for selected lines in 1973 (Table 6). The number of midge counted on resistant and susceptible plants was similar. Florets were taken from the four lines listed in Table 6, and midge eggs were found in each line.

In resistant lines, midge larva have been observed on maturing seed. The larvae were not covered by the glumes as they normally are but were fully or partially exposed. Billy Wiseman (personal communication, 1972) found that over 80 percent of the exposed larva completed their development and emerged as adults when the larvae were caged and left in the field.

From observations of F_2 populations, it appears that the midge resistance of TAM 2566 is controlled by more than one gene. Damage scores of several hybrids are presented in Table 7. TAM 2566 hybrids were damaged much less than the susceptible checks. The early blooming of A Tx 378 X Tx 415 may have reduced the damage of this hybrid.

The type of resistance present in lines such as TAM 2566 has not been established -- it does not appear to be nonpreference for oviposition, since large numbers of midge are present on blooming heads and they do lay eggs. However, the relative number of eggs layed among resistant and susceptible types has not been established.

Banks Grass Mite

The Banks grass mite is normally a damaging pest only on adult plants. Evaluation of lines for resistance is difficult because of the maturity-susceptibility interaction. Rarely does this pest damage sorghum until after bloom, with a rapid buildup of the mite and subsequent damage to sorghum occurring during and after seed filling.

Because the mite is normally a problem after the plants have bloomed, yield losses as a result of its feeding should be restricted to decreased seed size or losses due to plant lodging. We have evaluated lines first for their ability to maintain green leaves in the presence of large mite populations. Lines that are above average in this respect are then evaluated for their ability to maintain live stalks and near-normal seed size with mites present.

Grassy types such as 'Sweet Sudan' and 'KS 30' do not receive much mite damage. Observations indicate the mite numbers are not large on grassy types, possibly because each plant usually has several tillers that have not reached the bloom stage during mite buildups.

Table 6. Influence of midge resistance on midge numbers, Lubbock, Texas - 1973

Line		Damage score[1]	Number Midge/Head[2]
TAM 2566	(R)	1.9	25
IS 2579C	(R)	2.1	12
B Tx 3197	(S)	8.8	15
Tx 2536	(S)	8.5	19

[1] Same rating system as given for Table 3.
[2] Mean of 5 heads from each of 4 replications.

Table 7. Midge damage to hybrids of susceptible by resistant lines

Hybrid	1973		1974
	Damage score*	Days to bloom	Damage score
A Tx 3197 X TAM 2566	4.0	66	
A Tx 399 X TAM 2566			4.2
A Tx 618 X TAM 428	5.1	61	
A Tx 378 X TAM 428	5.0	62	8.7
A Tx 378 X Tx 415	6.3	58	9.0
A Tx 378 X Tx 2536	8.2	63	

*Same rating system as given for Table 3.

Table 8. Evaluation of selected sorghum lines for resistance to Banks grass mite

Line	Bloom date	Percent leaf death	Percent stalk death	Percent change in 1000-seed weight*
SC 599-6	8-6	40	25	-14
SC 56-6	7-21	57	64	14
B Tx 378	8-5	97	94	-35
Tx 7000	7-31	97	84	-30

*Difference in seed weight of each line grown at Pecos with high mite populations and the same line grown at Lubbock with no mites present.

Two lines -- SC 599-6, a partially converted 'Rio' selection, and SC 56-6, a partially converted IS 12568 selection -- have shown mite resistance in preliminary tests (Table 8).

Both SC 599-6 and SC 56-6 maintain more green leaves and healthy stalks much longer than most lines. This has been observed over several years and locations. SC 599-6 is also higher in sugar than standard grain sorghums. These observations suggest that selection for the most nonsenescing types with high sugar content in the stalk during grain filling may be effective tools in evaluating sorghum for resistance to the Banks grass mite.

Breeding Methods

Breeding methods that seem appropriate for the arthropod pests discussed in this paper are outlined below.

Midge and Banks Grass Mite

Pedigree Method

1. The highest level of resistance should be transferred to agronomically acceptable types by hybridization and selection.
2. Agronomically acceptable lines with the least susceptibility to midge should be used as the nonresistant parent, for example, TAM 428.
3. Grow a large F_2 population, at least 4,000 plants. Selection is most efficient under midge infestation; however, selection can be accomplished without midge being present. Limited experience has shown that selection for small glumed types should increase the frequency of midge-resistant types from the F_2 populations.
4. Evaluate F_3 rows under large midge populations. To increase the probability of large midge populations during blooming of this material, it should be planted at more than one date or location.
5. Evaluate F_4 selections in replicated progeny rows and backcross superior plants if necessary.

Population Breeding Method

1. Selection of the proper genetic male sterile may be critical in establishing the population (ms_3 has been found to be satisfactory). Antherless has not always been successful for use in the tropics.
2. Four types of populations should be established:
   a. For "rapid" progress, B (non-restorer) and R (restorer) populations should be established combining acceptable agronomic types and high levels of resistance.

b. For long range improvement in levels of resistance, populations should be established using elite varieties from the area in which the material will be utilized and all resistant sources available.

3. Utilize the appropriate selection scheme best suited to the area, such as mass selection, reciprocal recurrent selection and so on.

Greenbug

Pedigree Method

1. Select lines with the highest level of resistance suited agronomically to the area of intended use, which will be hybridized with elite adapted varieties.
2. Backcross F_1 plant of cross between resistant and susceptible line.
3. Evaluate large F_2 populations of cross between F_1 and elite susceptible variety. Use either seedling evaluation, transplanting resistant types to the field, or evaluate F_2 populations in the field.
4. Backcross resistant F_2 plants or select for evaluation in F_3 rows depending on agronomic desirability of the plant.

Population Breeding Method

The same basic plan outlined above for midge resistance breeding should be used for greenbugs.

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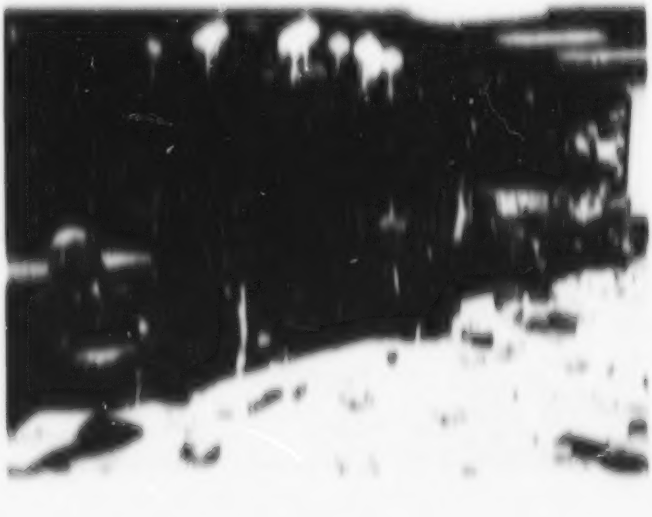
Fruit Crops Pest Management



MONITORING FIRE BLIGHT BACTERIA OF PEAR FOR DISEASE CONTROL

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In California there are 1,800 hectares (approximately 45,000 acres) of pears that produce an annual crop worth 70 million dollars. A pest management program was initiated in 1970 and has involved many people including farm advisors, technicians, pomologists, plant pathologists and entomologists.

The program has been very successful and over half of the total hectares of pears are now under pest management. The principal aim was to develop a pest management program and then turn it over to private enterprise. There are presently four agricultural firms that are offering pest management services at the rate of $20-$30 per hectare. The growers are generally pleased with this arrangement and consider it profitable for them to pay for the services.

Only the disease aspect of the program will be discussed here and not the entomological facet. The principal disease of pears in California is fire blight, caused by the bacterium *Erwinia amylovora*. It can be a devastating disease and is the primary reason why pears cannot be grown in most states. Under favorable climatic conditions for disease development, the disease can attain epiphytotic proportions in a few days.

In California, the disease infects flowers, becomes systemic and kills twigs and small limbs. It may kill the entire tree if diseased wood is not removed. Before our pest management program was established, control was effected by spraying the trees with streptomycin or fixed copper materials commencing at bloom time and every 5 days thereafter, until flowering was over. As many as 15-20 applications of spray material may be applied during the spring at $20 per application.

It frequently appeared that sprays were applied unnecessarily, since the climate was such in many years that disease did not occur. It was decided, therefore, to develop a system for monitoring the occurrence and population of fire blight bacteria in flowers to determine when sprays should be applied. This was to be related to weather conditions, such as humidity, temperature, dew point and rainfall, in hopes that eventually the occurrence of the bacterium in flowers and subsequent disease development could be predicted on the basis of weather alone.

To monitor for fire blight bacteria, a selective medium was developed to enable the bacteria to be isolated from the flowers and to be differentiated from other colonies of bacteria that might develop on the medium. Fire blight bacteria can be recognized on the medium by the typical orange-red hue of the colonies with transparent, entire margins.

In the preliminary stages of the pest management program, the following discoveries were made by using the medium to examine pear flowers in the field: (1) that *E. amylovora* occurs epiphytically in flowers and infects only during certain environmental conditions and that flowers may harbor up to 10^7 bacteria per flower and remain healthy; (2) that the bacterium does not colonize flowers under certain (cool) weather conditions; and (3) that insects readily disseminate the bacteria and frequently carry up to 10^7 cells per insect. Streptomycin-resistant strains in pear orchards were discovered in 1971. Today, about one-half of the total hectares of pears are affected.

After obtaining these results, monitoring began on a large scale for the occurrence of the bacterium in flowers. Two hundred flowers were picked at random over a 2.5-hectare area, placed in 100 ml of water and the washings plated on the selective medium. This was done every 3 days in 67 different locations by farm advisors and their assistants over a 4-year period as soon as flowering began in the spring. The selective medium plates were then collected and mailed to our laboratory for determination of *E. amylovora* bacteria. Within 60 hours of picking blossoms, the grower was informed of the presence of the bacterium in his orchard. The time from blossom collection to positive confirmation was recently reduced from 60 hours to 2 hours by the use of immunofluorescence.

The farm advisor kept detailed information concerning temperature, rainfall, dew point and various cultural practices and mailed these data to the laboratory weekly. In this way, the occurrence of bacterial colonization and infection were related to weather and other factors.

It was found in the 4 years of the monitoring program that growers frequently applied sprays when the bacterium was not present in flowers. As many as 15 sprays were often applied needlessly. Bacterial infestation usually occurred after a certain mean temperature was attained in the orchard. The bacteria are never detected before the mean temperature meets or exceeds the points delimited by a sloping line from 16.6°C on March 1 to 14.6°C on May 1.

Thus, it is believed that the occurrence of bacterial infestation can be predicted on the basis of weather conditions. Using the monitoring system, the number of bactericide applications in 16,000 hectares of California pears has been reduced on an average of three to five times. This represents a savings of approximately $20 per application per hectare, or a total savings ranging from $960,000 to $1,600,000 for the pear industry.

AN INTEGRATED SYSTEM FOR APPLE PEST MANAGEMENT

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Of all the deciduous fruits grown in the United States, apple has the most numerous and varied pest problems. There are approximately 500 insect and mite species known to feed on apples, plus a number of fungal, bacterial and viral disease organisms which can be damaging to trees and fruits (3). We not only have our native pests to contend with--such as apple maggot, *Rhagoletis pomonella* (Walsh); redbanded leafroller, *Argyrotaenia velutinana* (Walker); plum curculio, *Conotrachelus nenuphar* (Herbst) and others--but also such Eurasian species as codling moth, *Laspeyresia pomonella* (L.); eye-spotted bud moth, *Spilonota ocellana* (Denis & Schiffermüller); and European red mite, *Panonychus ulmi* (Koch).

An indication of the major apple pests of New York and their time of activity is shown in Figure 1. As you can see, at most times during the growing season, one or more insect, mite or disease organism is active, and some control measure may be required to protect the trees and/or fruits.

Current crop protection practices for apples in New York can be classified in one of the following four categories:

1. Full spray schedule--application schedules are designed to control all pests under all conditions.
2. Reduced spray schedule--application schedules and materials used are adjusted according to pest levels and need.
3. Integrated spray schedule--application schedules and materials are adjusted to permit biological control agents to function.
4. Apple Pest Management spray schedule--a combination of methods 2 and 3.

In 1973, the Apple Pest Management Project was initiated in New York to determine if a system could be established to integrate all useful known and new pest management techniques. A second objective was to determine if New York fruit growers could reduce their pesticide use through efficient pest management without reduction of the quality and quantity of fruit. Furthermore, the program was designed to train a core of specialists in fruit pest management to continue and expand the practices demonstrated in this system.

System Initiation

In the initial year of the program, 1973, personnel were trained and grower spray practices catalogued. Systems for orchard sampling and data organization were established. In the second year, 1974, a system of on-farm advice was developed on a limited basis involving 16 growers in a 5-square-mile area.

In 1975, the third year, the project was expanded to include more growers and explored two approaches to on-farm pest management advising. The first approach involved a total farm advisory program on all apple pests beginning with pre-season grower conferences and strategy meetings and full in-season grower advice and consultation. This service was conducted in a 5-square-mile area of Wayne County involving 16 growers. The program was carried out by farm advisors who had been trained in insect, disease and mite management by research and extension personnel. Scouts assisted the farm advisors with traps, weather stations, leaf samples and mite brushing.

In the second approach, a field scout assisted a regional fruit specialist in offering pest management advice. This was conducted with 22 growers in the fruit counties west of Rochester, New York. The scout gathered information and made observations on portions of the 22 farms and brought the data to the agent on a daily basis. The specialist then interpreted the data and rendered the necessary advice to the growers.

Monitoring for Disease

Apple Scab

The New York program is based upon continuous monitoring of orchards for pertinent weather data, pests, chemicals and beneficial organisms. For example, current pest management strategy for apple scab is based upon control of the primary ascospore stage. For the grower to do this properly, he or his advisor must know the maturity of ascospores in the overwintering leaves and the potential for their release should a rain occur. The relative number of spores released during rains, the length of time the foliage is wet and the temperature during wetting determine whether or not a scab infection takes place and its probable severity. In 1975, a scab spray advisory service was provided growers based upon monitoring of these events. A computer model for predicting ascospore maturity was established. Accurate predictions of the potential for spore release were made on a routine basis through the use of a "shooting tower" (2) in which overwintering leaves harboring the mature asci were subjected to a simulated rainfall. An examination of tapes and rods from various spore traps allowed us to determine the relative abundance of spores released during rain.

Leaf wetness meters and thermographs permitted us to determine if and when infection periods occurred. All of this information provided a sound basis for an assessment of the need for a fungicide application for scab control either before or after a rain.

Fire Blight

Fire blight, another major disease, is controlled best in New York by sprays in or near the bloom period. In 1975, this disease was monitored by swabbing overwintering cankers and washing blossoms. These were cultured, and if the bacteria were present and weather conditions were favorable for their spread, growers were advised of proper spray timing.

Monitoring and Control of Insect Pests

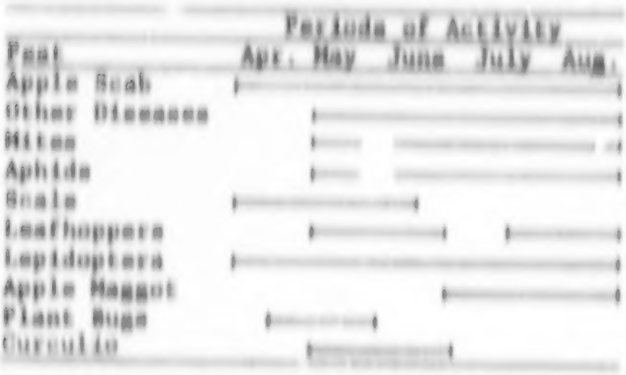
The most important insect pest on apples in New York is the apple maggot. This insect, the codling moth and several other pests which attack the fruit directly have been controlled so well that they are not present in most of our commercial orchards. However, they are ever-present in nearby wild or abandoned trees. Our control strategy was to prevent these insects from becoming established in commercial orchards. Sex pheromone or other attractant-baited traps were employed to detect invasions. For the apple maggot, a yellow sticky bait trap placed in strategic locations was used as a monitoring aid. The trapping data provided a guide for the efficient use of insecticides for maggot control.

Pheromone Traps

For several Lepidoptera, including the codling moth and certain leafrollers, the best tools for monitoring and predicting potential problems were sex pheromone traps. In 1975, these traps were used in several ways. In one case, a monitoring system was developed wherein traps, placed on a 10-acre grid system, were checked weekly or daily for insect activity patterns. At each of the grid points, pheromone traps were placed for five different apple pests. A total of 313 monitoring points was checked each week, and 15 points checked daily. The daily traps were located in areas where chemical sprays had little influence on captures. All of the information was processed in a computer to provide information on insect emergence and activity patterns as shown in Figures 2 and 3.

Average catches of the oblique banded leafroller, *Choristoneura rosaceana*, flight during the week of June 16-23 are displayed in five different environments in Figure 2. Note the average of five moths

Figure 1. New York apple pest complex and periods of activity for each insect, mite or disease organism.



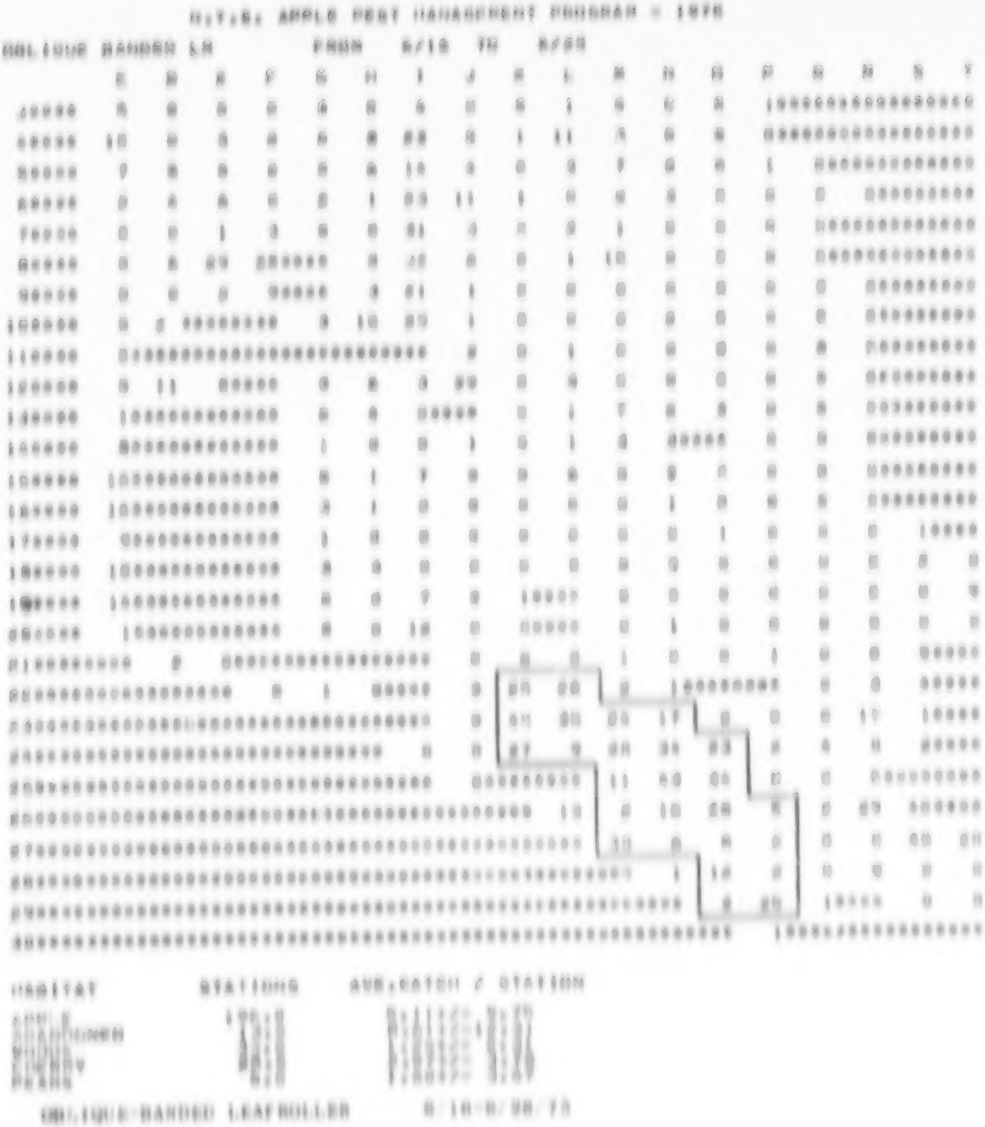


Figure 2. Computer print-out of pheromone trap captures for oblique banded leafroller for a 1-week period in a 5-square-mile area of Wayne County, New York. Area within black border consists of two farms where oblique banded leafroller caused fruit injury.

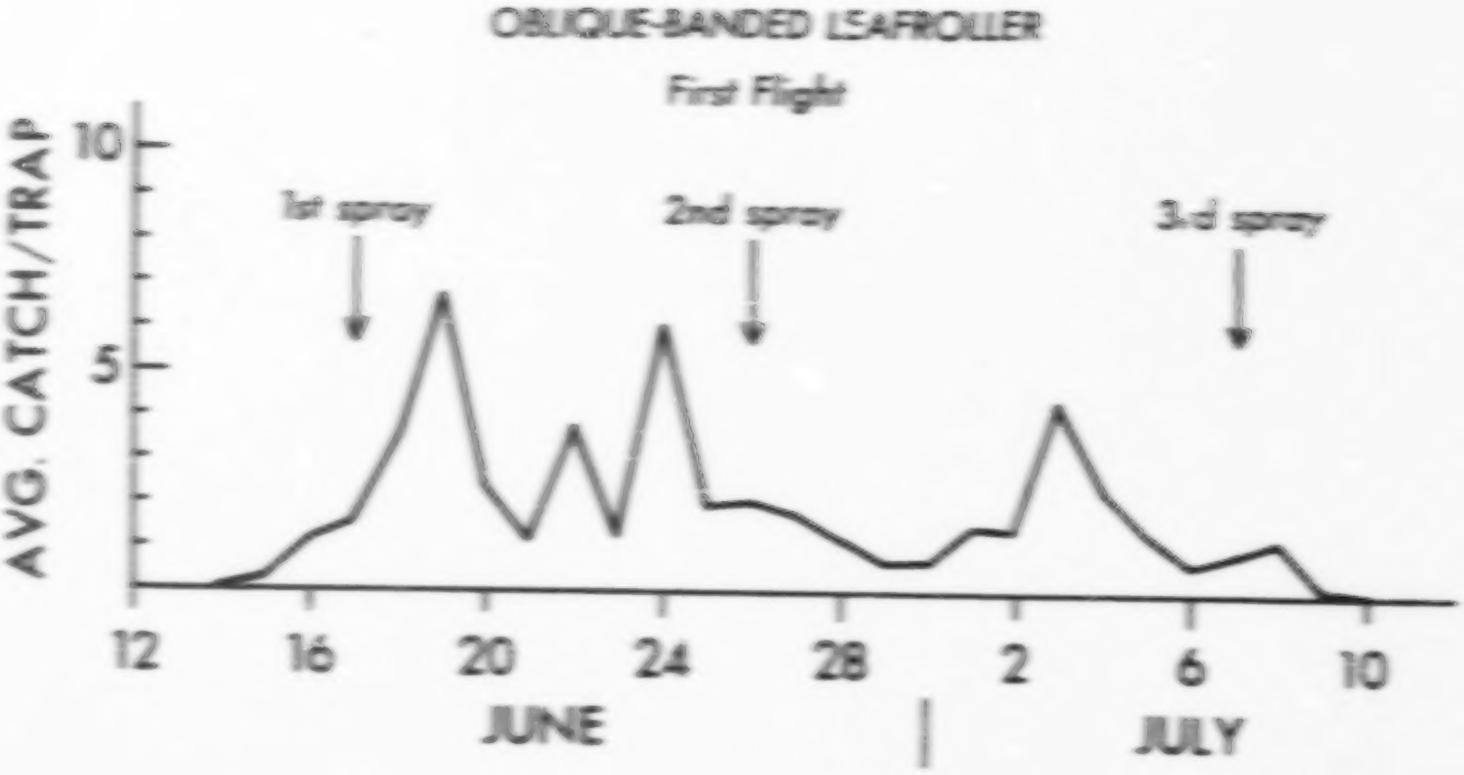


Figure 1. Oblique banded leafroller, *Choristoneura rosaceana*, first flight 1975. Average catches from 14 traps in unsprayed orchards. Insecticide applications (sprays) were timed to control adults and newly hatched larvae.

per trap in apple orchards. Examination of the entire print-out shows one area of commercial orchard where trap catches far exceed this average, indicating a population outbreak. Subsequent orchard inspections revealed this to be the case. One can also see that other commercial orchards in the area are relatively free from oblique banded leafroller problems because catches are at zero or below average. In cases where captures are zero, subsequent orchard inspections disclosed populations to be near zero. In the case of an insect such as codling moth, which is not present in most commercial New York orchards, the pheromone trap data assisted in locating sources of outside infestations. The highest trap captures for codling moth occurred in or near abandoned unsprayed orchards. Finally, information gathered from the daily traps provided an emergence pattern for the insects. Spray applications, if required, could be properly timed. For example, in the case of the oblique banded leafroller, some growers were alerted to the presence of overwintering larvae in their orchards in early June. In most instances, the last instar larvae are so tightly wound and webbed in leaves that only drenching of the trees will remove them. Our pest management strategy called for control of the adult flight and first larval hatch. Daily pheromone trap captures pinpointed emergence of this insect, and sprays were applied as shown in Figure 9. The pheromone traps thus provide insect emergence patterns, early warnings as to population outbreaks and indications of outside sources of infestation.

Predators and Beneficial Insects

Another key ingredient of our overall program was the development of predatory mite and beneficial insect populations. One of the chief predators of European red mite in New York orchards is *Typhlodromus pyri*. This mite predator differs from related predators found in other deciduous fruit-growing areas in that it is not as voracious a predator and does not reproduce quickly. On the other hand, it does have an advantage over some other mite predators, such as *Amblyseius fallacis*, in that it overwinters in the tree and is present in the tree from bud break on. *A. fallacis* also is present in a few New York plantings. Careful laboratory and field research have provided the pest management program with definitive data on the effect of apple pesticides upon these predatory mites (5). Through careful observation and much leaf brushing and counting, the capacity these predators have for suppressing or reducing European red mite populations has been learned. Chemical programs can thus be designed to encourage the development of these predators. Furthermore, the potential for control through leaf brushing and counting can be quickly estimated. It has yet to be determined whether the Michigan model (1) for mites can be adopted to the New York mite predator-prey complex.

Visual Monitoring

Another example of efforts to effect biological control was with the woolly apple aphid, *Eriosoma lanigerum* (Hausmann). This insect is present in all orchards at low levels and occasionally reaches epidemic proportions, apparently in response to the spray program. Careful observations through visual monitoring permitted determination of the presence or absence of a small dipterous parasite, *Aphelinus mali*, which effectively controls the woolly aphid. Observations of this parasite can be quickly relayed to the grower attempting to decide whether to spray.

Many insect pests, such as plantbugs, aphids, leafhoppers, scale and fruitworms, still were monitored most effectively through old standard sampling methods, such as emergence cages and orchard inspections.

Results and Discussion

The uniqueness of the New York program has been the development of a system of rapid orchard pest evaluations and quick transferral of this information back to growers. Growers were able to assess their orchard situations on a daily basis through a telephone reporting system available to them 24 hours a day. Furthermore, they were visited at least once a week by pest management personnel for consultation and spray record upkeep. Another service provided proper calibration and adjustment of spray rigs, together with information on crop development.

In examining results to date, it has been found that one of the most costly pesticide treatments applied by growers in New York is for European red mite control. Pest management strategy calls for control of this mite in the early season just as the overwintering eggs hatch. If a grower misses this application, a petal fall application is called for. In 1975, a very warm prebloom period caused red mites to develop sooner than normal so that target forms such as nymphs and adults were not present at petal fall. Thus, a petal fall application of a miticide would have been of little or no value to growers. The best time to apply a miticide in 1975 was approximately 10 days after petal fall. Growers who did not follow pest management advice and applied a miticide at petal fall were still faced with a mite problem 10 days later and had to make another application. Not only did they waste an application at the cost of approximately $12 per acre, but they also placed unnecessary pressures on the predator mite complex which was developing at that time.

The impact of the pest management program on growers' pesticide practices is best seen in Tables 1 and 2 (4). In examining these tables, special attention should be given to dosage equivalents of pesticides. These are calculated by dividing the rate per acre of each pesticide used by the recommended rate for that material at the time used.

Table 1. New York State Apple Pest Management Program, 1975. Growers in Wayne County[1]

Number, growers	Number, acres	Dosage equivalents			Pesticide cost/acre	Number, sprays	Percent of fruit		
		Insecticide	Miticide	Fungicide			Clean	Insect damage	Scab
Growers within pest management project area									
Growers who followed advice closely									
6	657	4.7	1.5	11.2	$64.06	8	94	4.1	1.7
Growers who followed advice in part									
4	438	4.7	1.1	12.8	$79.59	9	83	1.8	15.4
Growers who did not follow advice									
4	221	5.8	1.8	17.8	$96.29	11	94	1.3	4.3
Growers outside pest management project area[2]									
13	313	6.0	1.4	13.3	$88.98	12	96	2.0	2.0

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[1] Tette and Glass, 1976

[2] Growers selected by Wayne County Cooperative Extension Fruit Agent, Eugene [illegible].

Table 2. New York State Apple Pest Management Program, 1975. Growers in Monroe, Orleans and Niagara Counties[1]

Number, growers	Number, acres	Damage equivalents Insecticide	 Miticide	 Fungicide	Pesticide, cost/acre	Number, sprays	Percent of fruit Clean	 Insect damage	 Scab
Growers who followed advice closely									
9	362	3.9	3.9	9.0	$ 56.64	8	93[2]	3.0	4.0
Growers who followed advice in part									
5	66	5.8	1.5	13.0	$ 98.02	9	85	3.0	2.0
Growers who did not follow advice									
7	91	7.7	1.6	17.1	$124.33	11	90	0	2.0

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[1] Tette and Glass, 1976.

[2] Average of only six growers. Fruit on three farms was harvested before analysis could be made.

The sums for each class (insecticides, fungicides and miticides) have been calculated for the several blocks on a farm, and these have been average for each grower. The dosage equivalents given in Tables 1 and 2 are the averages for each group of growers. The dosage equivalents provide a convenient conversion to a common base for comparing amounts of pesticides that are normally used at different rates per acre. For example, the standard rate of polyram is 6 pounds per acre and for benomyl, 1 pound per acre. If grower A applied polyram seven times in a growing season at 5 pounds per acre, he would have used 35 pounds of fungicide. If grower B applied 6 applications of benomyl at 1 pound per acre, he would have applied only 6 pounds of fungicide. When comparing fungicide use, a distorted picture is presented if 35 pounds is compared to 6 pounds. Rather, a comparison of dosage equivalents is more; for example, grower A applied 5 pounds per acre in seven applications (5/6 X 7) for 5.8 dosage equivalents, while grower B applied 1 pound per acre in six applications (1/1 X 6 for 6.0 dosage equivalents. Growers who followed pest management advice in the farm advisory system (Table 1) used less pesticide in all three categories when compared with growers who did not follow pest management advice.

In the second pest management system, where growers received advice from a county agent, it is again found (Table 2) that growers receiving and using pest management advice use[illegible] pesticide in all three categories when compared with growers who did not follow pest management advice. In general, growers in both categories have the same quality fruit.

The results in Tables 1 and 2 are only a 1-year comparison (4). It was impossible to separate the influence of the pest management program on "growers not following advice" within the project area and growers outside the project area. Furthermore, growers' philosophy to crop protection varied greatly, and there was no way to evaluate possible skewness as a result of random selection of growers outside the project area. Finally, caution should be used in interpreting the results in these two tables, but every indication points to the fact that most growers can realize substantial reductions in the use of pesticides through a farm advisor pest management system.

APPLE SCAB PREDICTIVE AND MONITORING SYSTEMS

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Although apple scab has been studied intensely in the United States since the early 1900's (2,5,7), the disease continues as a chronic problem, with severe losses occurring when weather is favorable for epidemics. In 1973, for example, weather was favorable for scab in Michigan, and despite the extensive use of fungicides, about 13 percent of the state's production was infected with apple scab. Contributing to the failure to maintain control of apple scab has been the ability of the scab fungus, *Venturia inaequalis* (Cke.) Wint., to develop tolerance to dodine and benomyl fungicides which, when they were introduced, were considered more effective for scab control than previously available fungicides.

In the program at Michigan State University, some of the early work on the biology of apple scab is being reassessed in an effort to determine how available control methods can be used to better advantage. In this effort, predictive methods that use data from environmental and biological monitoring are emphasized as the basis for disease predictions. Computers and modern communication methods are used to deliver the predictions and control recommendations to fruit growers.

Monitoring Ascospore Discharge

The apple scab fungus overwinters in apple leaves on the orchard floor. Infection may occur when perithecia, produced by the scab fungus in the leaves, discharges ascospores upon wetting by rain. Discharge usually starts when fruit buds begin to open, peaks at about the pink stage of bud development and ends about 4 weeks after the petal fall stage of bud development.

Most systems for timing apple scab control measures utilize disease predictions based on the duration of leaf wetness, the mean temperature and the growth stage of the apple tree (9). In making predictions, ascospore density or intensity is always assumed to be heavy. Thus, a severe infection period may be predicted when the spore density is in fact quite low. An economical and simple system for monitoring ascospore discharge was developed at Michigan State. In addition to supplementing scab warning services based on duration of wetness and temperature, the method could be used for estimating ascospore densities in fungicide testing programs and possibly for monitoring spore discharge by other pathogens.

Rotorod spore samplers (Metronics Associates, Palo Alto, California) were used to follow discharge of apple scab ascospores from bud break in spring through early summer. Rotorod samplers were selected because they were inexpensive, simple to maintain and operate, reliable and capable of detecting low densities of ascospore (12).

As a result of studies over several growing seasons, it was found that the relationship of ascospore maturation and discharge to tree development may vary significantly from season to season. Ascospore maturity, for example, was sometimes well ahead of tree development, and high levels of inoculum sometimes existed at bud break rather than at the pink stage. In unusually late seasons, ascospores may not be plentiful until bloom or later. Years in which ascospore discharge varied the most from the usual pattern were often the years when apple scab control was troublesome.

Computerized Forecasts of Scab Infection

A system to predict apple scab infection periods was developed by Mills and is still used in many countries, including the United States. Mills' system (9) is based on the duration of wetness of the foliage and fruit and on the average temperature during wetness periods. Basically, the system reflects how favorable the environment is for those spores that land on susceptible host tissue.

A computerized system has been utilized for 3 years in Extension efforts, wherein the results of field monitoring are used as a basis for predicting infection periods. Two computer programs written in FORTRAN IV computer language were developed for data input and analysis. The input program, WINPUT, accepts the environmental and biological data collected manually at several monitoring sites and stores the data on a permanent file within the computer for future reference. Temperature and relative humidity at 3-hour intervals, beginning time and duration of wetting, rainfall amounts and Rotorod sampler catches are entered on a daily basis from field stations using teletypewriters and standard telephone lines. An error routine in WINPUT checks for values out of range and a correction routine allows users to correct errors before the data are stored on disc files.

The analysis program, MILLS, utilizes the Mills infection table and relates the duration of wetting and the average temperature during wetting to infection severity. Wetting periods interrupted by less than 8 hours are considered additive. The program analyses the most recent 5 days' data and prints out daily maximum, minimum and average temperatures; time and duration of wetting; average temperature during wetting; an infection prediction based on the Mills table; and the relative intensity of ascospore discharge as determined by Rotorod sampler catches.

Results from the forecast system are supplied to fruit growers by district Extension horticultural agents through prerecorded 3-minute Code-A-Phone messages. Data transmitted from field stations also can be retrieved at the Michigan State University campus and postcard warnings developed for mailing to growers. A major difficulty with the computerized Mills system is that predictions are made only after meterological conditions favorable for infection have been fulfilled. This requires the availability of eradicant fungicides capable of controlling infection several hours after the beginning of the infection period. Because mercury fungicides can no longer be used on apples in the Unites and because tolerance has developed to some of the eradicant fungicides, after-infection control is now less practical than before.

Airborne Conidia and Scab Development

Soon after the ascospores infect leaves and fruit, apple scab lesions become evident on the surface at or near the point of infection. Conidia, produced in these lesions, are important to disease increase during the summer and fall.

High numbers of conidia occur in rainwater collected under trees with moderate to severe infection. Because of the abundance of scab conidia in rainwater and because of failures to detect significant numbers of conidia in air samplers, early workers (2,7) considered splashing rain as the primary method of spore dispersal.

The idea that scab conidia are not released under dry conditions has generally persisted in the United States, although research workers in England (6), Ireland (10) and Poland (1) were able to detect conidia in volumetric spore traps under dry conditions. Airborne conidia were common in dry air samples collected with a Burkard spore trap in a Michigan apple orchard during two growing seasons. The pattern for our catch of airborne spores was diurnal, with peak catch occurring early in the afternoon and with a minor peak later in the evening. Increases in scab lesions correlate well with increases in airborne conidia but not with infection periods based on the duration of leaf wetness from rain and temperatures as developed by Mills (9). Leaf wetness from dew, which develops almost nightly in mid- to late summer, is believed to last long enough for conidia to infect.

From a disease management standpoint, airborne conidia are probably important in the spread of apple scab to clean but unprotected orchards and in increasing the rate of spread within orchards. Unlike control programs for controlling infection from ascospores, fungicide controls for conidial infections cannot be timed by monitoring ascospore release or by other available predictive systems. Rather, control must be applied on a regular basis throughout the summer. Airborne conidia also contribute to late-season infection after the normal orchard fungicide program is discontinued, thus helping to insure overwintering of the fungus.

Monitoring for Fungicide Tolerance

The ability of the apple scab pathogen to develop tolerance to the fungicides used for its control is already well known, despite the fact that commercial control problems from tolerant strains did not appear until 1968. Szkolnik and Gilpatrick (13) reported tolerance to dodine in New York in 1969, and in subsequent papers, Polach (11) and Gilpatrick and Blowers (3) characterized the nature of this tolerance. MacNeill and Schooley (8) determined the mutation rate in *V. inaequalis* for dodine tolerance and that the level of tolerance in the mutants was similar to the tolerance levels reported by Gilpatrick and Blowers (3) for naturally occurring dodine-tolerant mutants. Yoder (15) compared Michigan with New York isolates and concluded that the least sensitive Michigan isolates were about one-half as tolerant as the least sensitive New York isolate.

Following a report from an apple pest management scout that a few of the growers were having difficulty controlling scab, scab cultures were obtained from these blocks and their sensitivity to dodine was determined, using a paper disc assay procedure. Dodine tolerance was found to exist in two orchards and the level of tolerance was similar to that found in an isolate from New York State (6).

Next, tolerance to benomyl was looked for. Scab control with benomyl has been excellent in Michigan since its introduction in 1973. However, Wicks had reported the presence of benomyl-tolerant strains of scab in Australia (14). The procedure used for detecting benzimidazole-tolerant strains was to cut leaf discs with lesions and to streak the discs sequentially across divided petri plates containing potato dextrose agar (PDA) in one-half and PDA supplemented with benomyl in the other half. Spores with extended germ tubes on benomyl-amended media were judged tolerant.

Benomyl-tolerant apple scab was identified in nine apple orchards in 1975. Tolerant stains grew on PDA containing up to 800 μg/ml benomyl, a concentration well above that used in the orchard for scab control.

Cross-tolerance to several fungicides with similar chemistry was demonstrated as well.

Benomyl is rather specific in its mode of action, and it is believed that because of this specificity, fungicide tolerance has been able to develop quickly. The current trend is to find and develop pesticides with such specific activity that they will control certain target pests but will have little or no effect on nontarget pests. The experience with benomyl suggests such specific compounds, if developed, will soon fail because of the development of tolerance by the target organism. It may be possible to develop management systems for manipulating pest populations in a way to allow usage of action-specific pesticides without the buildup of resistant populations. However, research is needed to test the effectiveness of such management methods.

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DEVELOPMENT OF AN INTEGRATED CONTROL PROGRAM FOR ORCHARD PESTS IN THE ARMENIAN S.S.R. BY USING A COMBINATION OF METHODS, INCLUDING INSECTICIDES, ATTRACTANTS AND SEXUAL STERILIZATION

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Because of the vertical zonality of the Armenian S.S.R. and the great variety of fruit crops, there also exists a great variety of pests which cause damage of various kinds.

In the Armenian S.S.R. the fruit crops are usually infested by *Laspeyresia pomonella* L., *Grapholitha funebrana* Tr., *Laspeyresia pyrivora* Dan., *Yponomeuta malinellus* Zell., *Y. padella* L., *Hoplocampa brevis* Kl., *H. testudinea* Kl. and *Grapholitha molesta* Busk. In addition to these pests, certain phytophagous mites, scale insects and mealy bugs also may damage the fruit crops. The most widespread and injurious pest is *L. pomonella* L. (codling moth) which occurs in all areas and zones.

Also important is *G. molesta* Busk. (oriental fruit moth), which was discovered in Armenia in 1972. Surveys and other measures have shown that its range is confined to the northeastern part of the Armenian Republic.

Our investigations have shown that if there is no pest control or if the measures taken are inadequate, damage to fruit crops in the Armenian SSR may range between 80 and 100 percent.

Considerable work has been done recently in the Republic to develop various individual components for integrated pest control in orchards. One of the important elements of such a program is the combining of several pest suppression methods into one total program of control.

Investigations conducted in the Armenian Institute for Plant Protection have shown that damage to fruit crops and varieties by first-generation codling moth depends on the type of orchard (mixed or the same kind of fruit) and on the varieties of the individual fruit crops.

In single-variety orchards located at great distances from each other, the codling moth seldom infests apricots, quince, plums, late pears and peaches. Instead, apples and early pears are heavily damaged. It has been established that during the developmental period of the first generation of codling moth different varieties may suffer a different level of damage according to variety. However, during the development of the second and part of the third generation all varieties suffer approximately the same level and type of damage. This is due to phenology of the host and, in particular, to the maturing of the fruit. Thus, there is a definite relationship between the phenology of the host plant and the susceptibility of fruits to damage by the codling moth. This provides evidence of the existence of a seasonal resistance to pests in fruit crops.

Before the above-mentioned patterns were discovered, treatments of DDT and carbaryl were applied 6 or 7 times to the farms and orchards of the Ararat Valley. After the discovery of a seasonal pest resistance in the different varieties and types of fruit crops, stronger insecticides (Phosalone) have been used, as well as sex-lures and pheromones. Pheromones have been used for the purpose of better identifying the time in the season when control is needed for the codling moth. The combined use of these methods has reduced by one-half the number of chemical treatments needed to control the pest without lowering the effectiveness of control.

Experimental data for 1967-74 show that pest-inflicted damage to fruit under the reduced chemical treatment schedule was no more than when the full season chemical treatment program was used for either windfall or regular cropping patterns. For Renette Simirenko apples treated seven times during windfall percentage of damage inflicted by the codling moth amounted to 8.3 percent. This was reduced to 0 percent with regular cropping and to 8.7 percent and 0 percent with a 6-fold level of treatment, the level of control of the pest being 83.9 percent. Nearly the same percentage of damage in windfall and regular cropping was recorded with reduced chemical treatment for Bamerunk pears, peaches and quince. The results of these experiments show that it is advisable to apply several types of chemical treatments depending upon the variety and type of fruit crop. These measures now have been adopted on a large scale with due consideration to the use of a combination of methods by zones. The result has been a 45-50 percent reduction in the amount of pesticides used.

Chemical sterilization of the codling moth was started by the institute in 1965. A number of alkylating compounds, derivatives of ethyleneimine, were tested. The chemicals were obtained from the All-Union Chemical-Pharmaceutical Research Institute (Moscow) and from the State Institute of Applied Chemistry (Leningrad).

The sterilizing substances were tested in different concentrations by feeding them to adults. Also, thiotepa was sprayed on caterpillars, pupae and adults. Thiotepa was the most effective sterilant of the codling moth adults producing 99.7 percent sterility when fed in concentrations of 0.1 percent or sprayed on the insects in concentrations of 1-3 percent.

The contact effect of this chemical was studied on caterpillars both in the laboratory and orchard. Paper-ribbon traps were soaked in an aqueous thiotepa solution of concentrations from 0.1 to 6.0 percent. The test results show that the most effective dose against caterpillars just prior to participation is a thiotepa concentration of 2 percent. This will produce sterility of 74.9 to 100 percent of the treated individuals. Sterility of the control group was 15.2 percent. Good results were obtained from contact-spraying the pupae with the thiotepa in a concentration of 1.0 percent with effectiveness of 100 percent.

In view of the considerable sterilizing effect of thiotepa on codling moths (contact or feeding) and of the possibility of attracting males into traps with virgin females, an experiment was conducted in the field against moths of an overwintered generation. This was done in an apple orchard over an area of 6.6 hectares. The objective was to sterilize the natural population. Traps were stationed in the test area baited with virgin females and sterilizing agents. The results show that this method when used against the first generation allowed an 11.8-percent damage to fruit on the tree and a 38.7-percent damage to fallen fruit (the control was, respectively, 36.7 percent and 75.4 percent). The second generation did not appear to be affected by this method of control.

In the integrated control of the oriental fruit moth, the use of synthetic pheromones is essential. Chemical and radiation methods of sterilization also must be used. It has been established that chemical sterilization of the pest can be achieved by contact-spraying, as well as by feeding. Maximum sterility (90-100 percent) is obtained by contact with thiotepa (0.1-percent concentration) for 10-30 minutes or with 0.1-0.2 percent dymatif for 1-2 hours.

This method of pest control can have an important difficulty if the individuals of each sex have to be separated and sterilized separately in large quantities. This is a cumbersome and time-consuming operation. It is therefore advisable to sterilize and release the moths jointly, males and females together.

There are many reports on codling and gypsy moth males being attracted to sterilized females. In the U.S.S.R., however, little was known about the codling moth. Tests revealed that the males, when selecting a sex partner, have a certain preference for sterilized females. This, of course, is advantageous in the case of a mixed release of sterile males and females since the sterile females, when released, compete successfully with the natural (nonsterilized) females and distract and lure away the males. Furthermore, the "sex appeal" of sterile females is extremely important when sex-lure baited traps are used as part of the control strategy.

It is extremely important that both thiotepa and dymatif in concentrations selected for practical use have no injurious side effects on the treated males, that is, that the viability and full activity of the males must not be impaired.

Laboratory tests have revealed that many Lepidoptera, such as oriental fruit moth in the adult stage, required additional feeding. This makes it possible to sterilize moths via intestinal absorption. Encouraging results have been obtained by feeding moths with a 0.1-percent aqueous concentration of thiotepa or a 0.2-percent concentration of dymatif in a cotton ball for 24 hours. The numbers of fertile parents was reduced by 90-100 percent.

One of the most important investigations in the field of integrated pest control against the oriental fruit moth has been sterilization by radiation. The first experiments of this kind by the Institute were undertaken in 1974. The pupae were irradiated with gamma rays of Co^{60} prior to emergence of the moths. The tested dosage was 20,000, 30,000, 40,000, 50,000 and 60,000 roentgens. Nonirradiated pupae of the same population were used as controls. It was found that concomitantly with the increase in radiation dose there was a decrease in the percentage of emergence and sterility of moths. There was also an increase in the sterility of eggs as well as a decrease in numbers of offspring.

Laboratory tests revealed that the sterilizing radiation dose for the Armenian oriental fruit moth ranges between 35,000 and 40,000 roentgens. These doses do not affect the life span of the moths or their sexual activity. Presently tests are being conducted to determine the optimal relations between sterile males and normal males on the basis of emergence frequency and on the basis of mass breeding of the pest on natural and synthetic foods.

The Institute also is investigating the possibility of using attractants against the codling and oriental fruit moth. In the case of the fruit moth, traps were baited with virgin females (5 to 10 per trap), with synthetic attractants made by Zoecon-USA, pheromones synthesized by VNIIKhSZR (0.1-percent concentration), and common molasses diluted in water (1:4 ratio). Common water was used as control. Tests were conducted in a peach orchard.

Surveys were conducted daily from September 1 to 23, 1974. The results have shown that the Zoecon substances had an excellent effect: in 23 days 890 males were caught (a daily average of 38.9), ranging from a minimum of 3 to a maximum of 90 individuals daily. By using virgin females (5 per trap), an average of 4.3 moths were caught daily; with 10 females, 5.0 moths were caught, with molasses 1.4 and with the control, none were caught. Better results (5 to 10 males) were obtained by using the VNIIKhSZR-synthesized pheromone in a 0.1-percent concentration. Higher concentrations were tested in 1975, but results are not yet available because the tests are still in progress. Somewhat lower results were obtained with molasses. An average of 1.4 individuals were caught every day.

Pheromones also were used for quarantine purposes to determine new foci of the oriental fruit moth in the Armenian S.S.R. These were used on farms of the Ararat Valley where it is impossible to use live virgin females as bait for fruit moth males. Observations were conducted every other day. But to date no oriental fruit moths have been caught in the traps. Consequently, so long as the distribution of the fruit moth in the Armenian S.S.R. is localized, the farms in the Ararat Valley stay completely free of the pest. At this time pheromones also are being tested for the purpose of determining the population dynamics of the pest, its density and daily flying activity and to devise better chemical control measures for flying moths.

Conclusions

In reviewing the results of many years of investigations conducted by the Armenian Research Institute for Plant Protection on the integrated control of the principal orchard pests of the Armenian S.S.R., the following conclusions can be drawn:

1. If the control of the principal fruit crop pests is lacking or unsatisfactory, damage to fruit may range from 80 to 100 percent. This can considerably reduce the yield and the quality of fruit produced in the Republic.

2. To control different generations of the codling moth, it is important to determine seasonal pest resistance of the fruit, the degree of damage to various varieties and types of fruits and the type of orchard involved. It has been determined that --

a. In single-variety orchards far removed from one another, apricots, pears, quince, late pears and peaches are almost unaffected by the codling moth; it follows that in such orchards the first two insecticide treatments should be omitted, while in apple and early pear orchards, such treatments are mandatory.

b. During the development of the first codling moth generation, the capacity for damage is different on different varieties of fruit, while during the development of the second and, in part, the third pest generation, all varieties are affected about equally.

c. Once the seasonal pest resistance of fruits has been established, choices may be made between the unilateral application of new, highly effective insecticides (carbaryl, Phosalone), or the use of sex traps or pheromones to determine the need and time for pesticidal control. Insecticide treatment also may be applied on a discriminate basis. This makes it possible to reduce the number of treatments by one-half without impairing effectiveness of pest control.

3. When codling moths are chemically sterilized, a near-100-percent effectiveness is achieved by feeding moths with a 0.1 percent solution of thiotepa or by contact-spraying pupae with a 1-3 percent thiotepa concentration.

4. When chemically sterilizing the oriental fruit moth, a 90-100-percent effectiveness in laboratory conditions was achieved by contact-spraying caterpillars with 0.1 percent thiotepa for 10-30 minutes and 0.1-0.2 percent dymatif for 1-2 hours, or by feeding the moths with 0.1 percent thiotepa or 0.2 percent dymatif for 24 hours.

5. Laboratory tests have shown that the sterilization dose of the Armenian population of the oriental fruit moth ranges between 35,000 and 40,000 roentgens (irradiation of late-age pupae with gamma rays from Co^{60}). These doses do not adversely affect the life span and sexual activity of the moths.

6. With regard to the trapping of oriental fruit moth males, good results were obtained by using pheromones. A total of 890 males were caught in 23 days.

7. Pheromones also may be successfully used for surveys to determine new oriental fruit moth breeding centers, the dynamics of its abundance, population density and daily flying activity of the moths and to determine the exact period when insecticides are needed to protect the fruit.

ALTERNATE METHODS FOR CONTROL OF THE CODLING MOTH

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The codling moth, *Laspeyresia pomonella* (L.), is the most destructive pest of apples and pears in most parts of the world (12). Indeed, the only country considered a major producer of these deciduous fruits in which the codling moth does not occur is Japan. This insect is injurious only in the larval stage in which it enters and feeds in the fruits. In North America, this insect has two or more generations per season in most fruit-growing areas and is univoltine only along the northern fringe of apple production.

Apple and pear production in the United States is valued at over $700 million. Most of this production is subject to infestation by the codling moth, and it has been estimated that without control measures over half of the apple crop would be unmarketable because of infestation by larvae of this insect. Even with current control measures, losses in fruit quality and quantity of 0.5-5.0 percent routinely occur because of codling moth. These losses are in addition to the costs of such control measures. These costs range from $25-$100 per acre per season, depending upon geographic location, crop and intensity of infestation. Using these estimates, the cost of the codling moth on these crops in the United States alone is some $39.2 million per year.

Scheduled applications of broad spectrum organic pesticides has been the most commonly used method for control of the codling moth in North America since the introduction of DDT in the 1940's, even though the use of more selective pesticides, parasites and predators, insect pathogens, cultural and other techniques has had limited commercial success. In a conventional program, from two to six applications of pesticides are required to achieve adequate control.

In recent years, advances in research on and implementation of integrated programs for the control of various pests affecting apples have resulted in more judicious use of broad spectrum and relatively selective organic pesticides, biological agents and cultural and other techniques for control of the codling moth and phytophagous mites (7, 8). In the western United States these integrated programs are based upon the chemical control of codling moth with reduced numbers of applications of pesticides and reduced dosages per application of selected pesticides. Judicious use of these pesticides allows naturally occurring or man-augmented populations of beneficial insects and mites to increase to the level where they can exert satisfactory control over pests such as phytophagous mites. However, even the implementation of these integrated programs does not yet allow for realisation of the full potential of biological agents and other techniques for control of different pests affecting these crops.

Need for the development of new methods of control for the codling moth is accentuated by many factors:

1. The codling moth is the key pest of apples and appears in most areas where these crops are produced, requiring preventive applications of pesticides each season to achieve satisfactory control.

2. Many of the pesticides used for control of the codling moth interfere with potential biological control of other pests.

3. Resistance to DDT now exists in most populations of codling moth; resistance to methoxychlor has been reported in Central and Eastern Europe; and, while no reports of resistance to organophosphorous or carbamate insecticides have been verified, the potential for development of such resistance certainly exists.

4. Current and future restrictions on availability and use significantly limit the options for use of pesticides in specific control programs. Growing concern for the quality of our environment and life style has and will continue to affect the manner in which pesticides and other control measures are employed.

5. Increased awareness that too great a reliance has been placed upon chemical pesticides for agricultural pest control has led to a consideration of balanced programs based upon judicious use of all available appropriate tools.

Sterility

One of the alternate methods for the control of the codling moth receiving a considerable amount of research emphasis, particularly in North America and Europe, is the sterility concept which was pioneered some years ago by scientists of the Agricultural Research Service of the U.S. Department of Agriculture.

The use of the sterility concept includes the rearing in the laboratory of large numbers of codling moths which are sterilised and released into the orchard in numbers sufficient to inundate the area, thus assuring a high incidence of mating between sterilised and native moths. The higher the incidence of such mating the greater the decrease of reproduction in the orchard. With all factors being favorable, eradication of a given population is theoretically possible and has been achieved with some pest species in some areas of their geographical range.

The feasibility of this technique for control of the codling moth was first demonstrated in the early 1960's in British Columbia, Canada, where releases of laboratory-reared, sterile moths were made into abandoned apple orchards (11). Additional successes were achieved in the United States in the mid-1960's in research conducted by scientists of the Agricultural Research Service in Yakima, Washington (3, 4, 15).

This autocidal method for control of the codling moth has had as its goals population suppression to sub-economic levels and/or eradication. In none of the ongoing research programs employing this technique for control of the codling moth has eradication been achieved, while population suppression to sub-economic levels, comparable to those achieved with conventional techniques, has been routinely reached (3, 4, 11, 15).

A relatively large field test of the sterility concept for control of the codling moth was initiated in Washington by USDA scientists in 1969 (3, 4, 15). This test was conducted in a 32-square-mile valley containing 432 acres (174.5 hectares) of commercial apple and pear orchards. Host tree and codling moth populations were surveyed and monitored in 1969 and 1970, and non-commercial host trees were eliminated as sources of codling moth through tree removal or spraying with insecticides. Populations in the commercial orchards were managed through applications of pesticides before the release of sterile moths in 1971. After initiation of releases of sterile insects, the use of pesticides in the commercial orchards in 1971 and 1972 was either drastically reduced or eliminated, depending upon the individual orchard and situation.

After the third year of this field study, it was concluded that, while populations had been reduced to sub-economic levels after the first 2 years of the program, the degree of suppression obtained in the third year, while commercially acceptable, was not as great as was expected. Research since the termination of this field test has emphasized the factors affecting potential success of the sterility concept for control of the codling moth: the effects of laboratory-rearing upon fitness of the reared moths, effects of radiation-induced sterility upon vigor and competitiveness of the sterilized insect, and differences in activity and behavior of various laboratory or native strains.

It is evident that in recognizing various factors which may affect the success of sterility as a means for control of the codling moth, several tools in addition to sterility should be blended to form a multifaceted approach to control. Such an approach would employ area-wide sanitation (elimination of non-commercial host trees as sources of codling moth), the application of pesticides to commercial orchards to control or reduce existing infestations before beginning releases of sterile moths and judicious use of pesticides during implementation of the release program to control isolated areas of intensive infestation. As research efforts in other areas of intensive infestation. As research efforts in other areas progress, other tools, such as pheromones, could possibly be blended into this program.

Pheromones

Live virgin females or extracts thereof were used intensively to attract male codling moths to traps for survey and monitoring purposes after the demonstration by USDA scientists in 1963 of the presence of a powerful sex pheromone in this species (2). In 1971, the isolation and identification of the sex pheromone was described by scientists of the New York State Agricultural Experiment Station, Geneva, New York (13). The isolation, identification and synthesis of this compound, *trans*-8, *trans*-10-dodecadien-1-ol (1, 9, 13), made feasible studies on numerous approaches to utilization of pheromones for direct control of the codling moth. Such approaches include mating disruption and male removal via trapping.

Disruption of communication between the sexes of the codling moth, the redbanded leafroller, the oriental fruit moth and other deciduous fruit insects has been achieved by exposure of adults in the field to high concentrations of their respective sex pheromones (14). In research conducted in 1973, 1974 and 1975 by USDA scientists in Yakima, Washington, communication between the sexes and subsequent mating of the codling moth was disrupted by exposure to excess concentrations of the pheromone applied as a spray to the orchard (10). The pheromone was formulated in microcapsules and applied by helicopter. At a 3 per acre rate, an 87-percent or greater reduction in response of males to pheromone-baited traps was observed for 7 days posttreatment. When two consecutive applications of pheromone were made at an interval of 8 days, a 95-percent or better reduction in numbers of males trapped was observed for 7 days after the first application and only a 64-percent reduction on the eighth day. The second application was made at this time and a 100-percent reduction in response was observed for the following 6 days. When the fruit was harvested, a 93-percent reduction in infestation in the treatment over that of the untreated control was observed.

Emphasis in research on this approach has been placed upon development of formulations with more satisfactory rates of emission of the pheromone and a longer duration of effect. A number of microencapsulated formulations of the pheromone have been prepared and have been tested or are currently under evaluation. At this time, none of these formulations has yielded the duration of effect considered necessary for initiation of larger scale field testing. In addition to microencapsulation, other types of formulations are being studied and developed for field evaluation.

Antipheromones

An interesting facet of mating disruption is the use of so-called mating inhibitors to disrupt communication between the sexes and subsequent mating. In research also conducted at Yakima, Washington, several compounds derived from the sex pheromone of the codling moth were found to disrupt communication between the sexes (5, 6). When the ratio of the pheromone and one of the more potent inhibitors in a trap was 33:1, a more than 96-percent reduction in numbers of males trapped over a 2-week period resulted. However, when formulations of this mating inhibitor were applied in an orchard at the rate of 6 g per acre (14.82 g per hectare), a 100-percent reduction in response of males to pheromone-baited traps was observed for the first 2 days posttreatment, and this fell rapidly to 69 percent by the third day and to 18 percent by the fifth day posttreatment. Other formulations of this mating inhibitor have been developed and field tested, but none have yielded a satisfactory duration of effect.

Mass Trapping

While male removal via mass trapping has shown considerable promise for control of the redbanded leafroller, *Argyrotaenia velutinana*, this technique has not as yet been successful with the codling moth. In research conducted in Washington, New York, British Columbia and Switzerland, mass trapping for control of the codling moth has enjoyed varying degrees of success. In Washington even with a trap density of three per tree, infestations could not be held to acceptable levels, though some effect upon the population was observed (10). Additional research on the development of optimally attractive concentrations of the pheromone and more efficient traps and information on the influence of trap and codling moth population density upon efficacy of the trap is needed for further testing of this control technique.

There are numerous other approaches to control of the codling moth under study at various research laboratories throughout the United States. Such approaches under study include host plant resistance, cultural methods, use of parasites, predators and pathogens, selective pesticides and insect growth regulators, among others. Space does not permit a further discussion of these potential alternate methods.

Discussion

There is a considerable need for the development and implementation of alternate methods for control of the codling moth. Those approaches now receiving the greatest amount of emphasis are integrated control utilising reduced applications of selected pesticides and reduced dosages per application of these selected pesticides; sterility, consisting of mass releases of laboratory-reared, radiation-sterilised moths; confusion by exposure of males to excess concentrations of the pheromone; and mating inhibition by exposure of males to compounds derived from the sex pheromone and which disrupt communication between the sexes. Successful implementation of one or any combination of these methods of control is dependent upon the availability of sufficient biological and technical data, the development of satisfactory formulations of the pheromone or related compounds and an increased level of financial support.

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PEST MANAGEMENT SYSTEMS FOR PHYTOPHAGOUS MITES AND THE CODLING MOTH

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In order to give an overview of how apple pest management research and extension delivery is organized and carried out in Michigan, it is necessary to present this discussion as a series of short abstracts. My objective in doing so is to describe a general approach to pest management research as well as to discuss the specific components of an apple pest control system. For those who have interest in more detail, I refer you to several papers which previously have been published on this research (2,3,4,6,18,19). For the purpose of organization, references will be made periodically to the system science or modeling approach as the underlying method which integrates the various topics discussed. The reader is referred to a more complete discussion of this method in relation to a Michigan apple pest management system which was presented at last year's USSR-USA symposium held in East Lansing, Michigan (6). In that publication the components of a pest management program were identified as a coupled feed-back system which included (1) a target crop pest-natural enemy ecosystem, (2) a biological monitoring or survey system for sensing the state of the biological elements, (3) an environmental monitoring system for assessing the influence of weather on the biological entities in question, (4) descriptive pest dynamic or management models describing the variable inputs which affect the densities of the biological species in time and space and (5) an implementation system for actually causing changes in the pest system so that management below a tolerable threshold level might be effected.

In this presentation, emphasis is placed on the complementary biological research which must accompany the engineering-related activities of modeling and systems design if the latter are to be useful and stresses the applied aspects of extension pest management delivery in the field.

Michigan Apple Pest Systems

The apple arthropod pest complex occurring in Michigan can be divided into 3 major groups. Firstly, there are several key insect pests including the codling moth, *Laspeyresia pomonella* (L.); the plum curculio, *Conotrachelus nenuphar* (Herbst); redbanded leafroller, *Argyrotaenia velutinana* (Walker); and apple maggot, *Rhagoletis pomonella* (Walsh). Each is a direct pest of the fruit and characteristically is without effective predators, parasites or diseases which provide for their biological control or regulation below densities that are tolerable. Each pest individually, and especially the entire complex, is capable of destroying a major portion of an apple crop if control measures are not applied on a seasonal basis (12).

A second group of insects referred to as periodic or potential key pests include such lepidopterous species as the fruit tree leafroller, *Archips argyrospilus* Wlk; eyespotted bud moth, *Spilonota ocellana* (D. & S.); oblique banded leafroller, *Archips rosaceana* (Harris); green fruitworm, *Lithophane antennata* (Walker); lesser appleworm, *Grapholitha prunivora* (Walsh); oriental fruit moth, *Grapholitha molesta* (Busck); and many other non-lepidopterous insects (16). These species will feed directly on fruit and are similar to those of the first group but differ in being more sporadic in attaining damaging levels and often are controlled by effective complexes of natural enemies or by insecticides applied for control of the pests in the first group.

Lastly, there are several complexes of arthropod species which feed predominantly on the woody or foliage portions of the apple tree. These species can be tolerated at moderate density levels without affecting the quality of the fruit produced. In most cases, they are attacked by complexes of natural enemies which provide biological control in unsprayed orchards, but in sprayed habitats, they are principally induced to pest status by the chemical destruction of their predators and parasites. They include such insects as the San Jose scale, *Aspidiotus perniciosus* Comstock; the apple aphid, *Aphis pomi* DeG.; the rosy apple aphid, *Anuraphis roseus* Baker; the woolly apple aphid, *Eriosoma lanigerum* (Hausmann); the white apple leafhopper, *Typhlocyba pomaria* McAtee; and the spider mites, *Panonychus ulmi* (Koch) and *Tetranychus urticae* (Koch).

Two Representative Apple Pest Subsystems

The development of management techiques for a pest complex usually depends on its division into smaller units, and for practical purposes, two representative subsystems associated with apples have been studied in detail. They are the complex of phytophagous mites including *Panonychus ulmi* (Koch), *Tetranychus urticae* (Koch), *Aculus schlechtendali* (Nalepa) and the codling moth, *Laspeyresia pomonella* (L.). Study of phytophagous mites has been emphasized because they are indirect pests and have considerable potential for biological control, much is known of their dynamics and interactions with predators (13) and the influence of pesticides on these pests and their natural enemies is well understood (4). In contrast, the codling moth was selected because it is a direct fruit pest which has little potential for control below economic levels by biological means. It has been extensively studied with regard to its biology, and hence, there is considerable data available in the literature which is helpful in designing a management system. Although it has dispersal features which make it difficult to study, a recently identified pheromone when placed in a sticky trap (18,20) provides an effective tool for sampling populations which occur at low densities. Also, it is the only direct fruit pest occurring in Michigan which is widely distributed in other fruit-growing areas of the world.

In the remaining portions of this paper, several major research and extension delivery programs which have been developed for these two pest systems are discussed in relation to the component stages of an on-line pest management system alluded to earlier.

Modeling

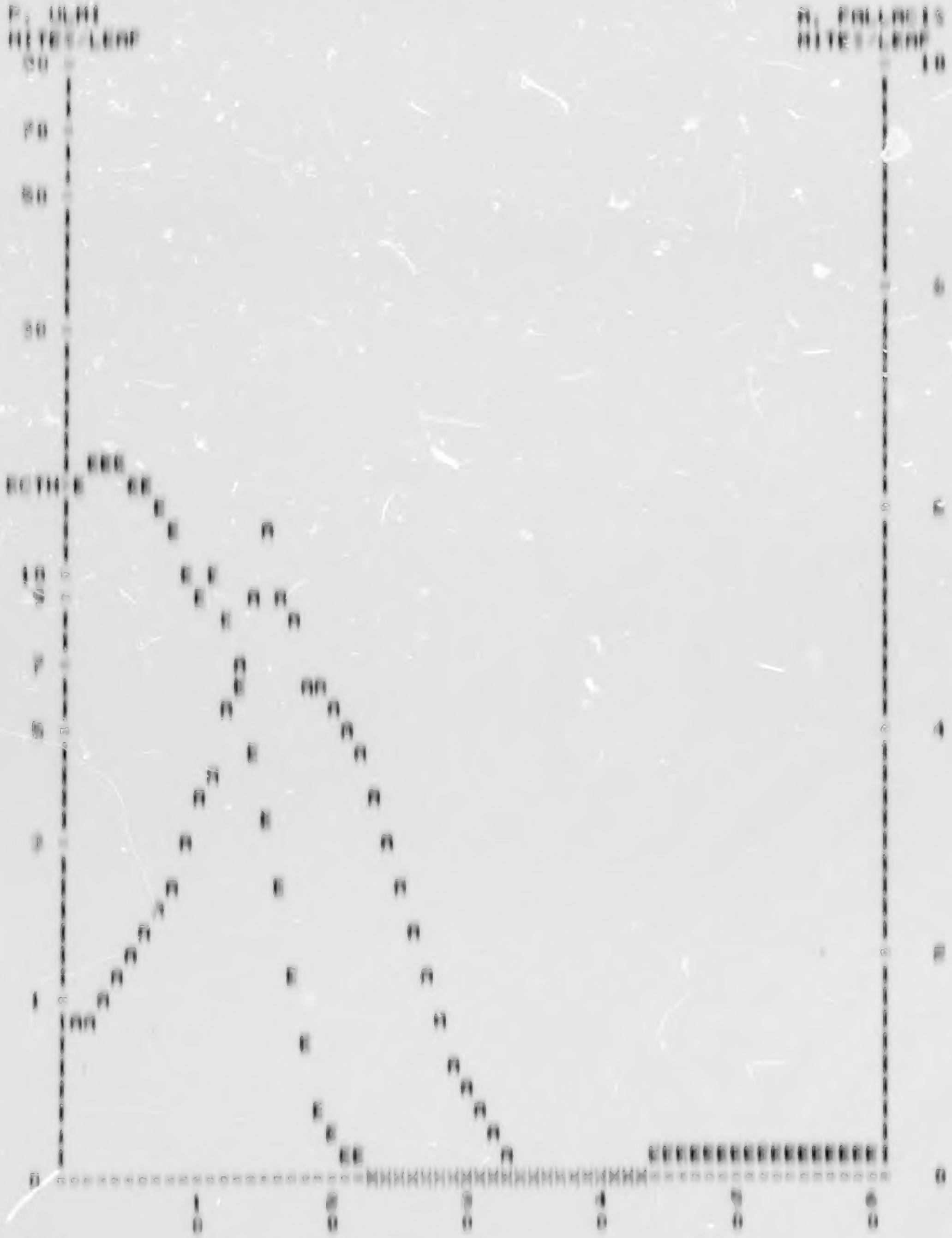
As noted, a detailed publication describing the modeling programs which have been developed for both plant feeding mites and the codling moth has previously been presented to the USSR-USA conference (6). The basic inputs and outputs of each model are summarized beneath the two headings below.

Plant-Feeding Mites

This model simulates the population dynamics of the European red mite and its principal predator, the phytoseiid mite, *Amblyseius fallacis*, within a growing season; it is more detailed and sophisticated than that described for the codling moth. Model inputs needed to use this system are current or real-time weather received daily from a 27-site National Oceanic and Atmospheric Administration (NOAA) network located throughout the Michigan fruit belt and stage distribution and density counts of spider mites and predators taken early in the season from a 10-acre block where pest mites are just beginning to increase. Model outputs include predictions of the dynamics of both species on a time/density scale (Figure 1), statements about the probability of biological control occurring without the aid of selective acaricides and "and/or" rate recommendations for applying a selective spray to establish a more favorable predator-prey ratio (see Croft *et al.*, 1976b for more details of this program).

Codling Moth

This model utilizes pheromone trap catch data taken in early season as reference points and couples them with a physiological time model which forecasts critical events (egg hatch, emergence, damage and so on) for spray timing. Inputs needed to use the model are first trap catch



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EP REACHED A PEAK OF  1671.0 ON DAY  2

AF REACHED A PEAK OF   579.0 ON DAY 15
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Figure 1. Simulation output of a *Panonychus ulmi*-*Amblyseius fallacis* interaction model.

(Biofix I), and peak catch (Biofix II) from the spring moth generation (Riedl *et al.*, 1976). When coupled with on-line weather inputs, this system provides output options including predictive statements of development, maps (SYMAP, Figure 2) of development and forecasts of life stage changes for the two generations of moths occurring at 27 sites across the Michigan fruit belt (see Riedl *et al.*, 1976 for greater detail on this program). The above described timing model is only a part of a more complex population dynamics system presently under development which relates pheromone trap catch data to population density estimates (17,18).

As indicated by the two prototype systems described above, models can provide predictive information about the behavior of a pest population and how a pest can be managed, or by sensitivity analysis and validation studies, they can give valuable data on the additional types and the quality of biological data which is needed to improve the description of the system being studied. In essence, there is a two-way flow or an iterative process going on between the modeling and biological research; as one is improved, it provides input as to how the other should be directed until a sufficiently sophisticated system for pest management is developed. In the ensuing portions of this presentation, several biological research projects which were developed concurrently with modeling studies are reviewed.

Inter- and Intraspecific Dynamics -- The Pest-Natural Enemy or Pest Ecosystem

Plant-Feeding Mites

For the past 5 years, detailed studies have been conducted to assess the basic interactions of within-tree and groundcover populations of the principal pest species, *Panonychus ulmi*, *Tetranychus urticae* and *Aculus schlechtendali* and the most important predators of these prey species, *Amblyseius fallacis*, the stigmaeid mites, *Zetzellia mali* (Ewing) and *Agistemus fleschneri* (Summers), and the coccinellid, *Stethorus punctum* (LeConte) (8). Only those associated with the most important predator, *A. fallacis*, and certain interspecific interactions between the pest mite species will be commented on here.

In Figure 3, several generalized types of interactions are shown between *A. fallacis* and *P. ulmi* and *A. schlechtendali* in the apple tree. In several cases the use of selective acaricides has influenced their dynamics. Figure 3a is a plot of field-collected sample data where an effective ratio of *A. fallacis* to spider mites (0.40:2.0/leaf) is present in early season, and predators provide complete biological control of spider mites before the latter exceed five per leaf. Figure 3b shows a less effective ratio of predators to prey (0.25:8.0/leaf), and in this case pest mites reach a density of almost 20 per leaf before control

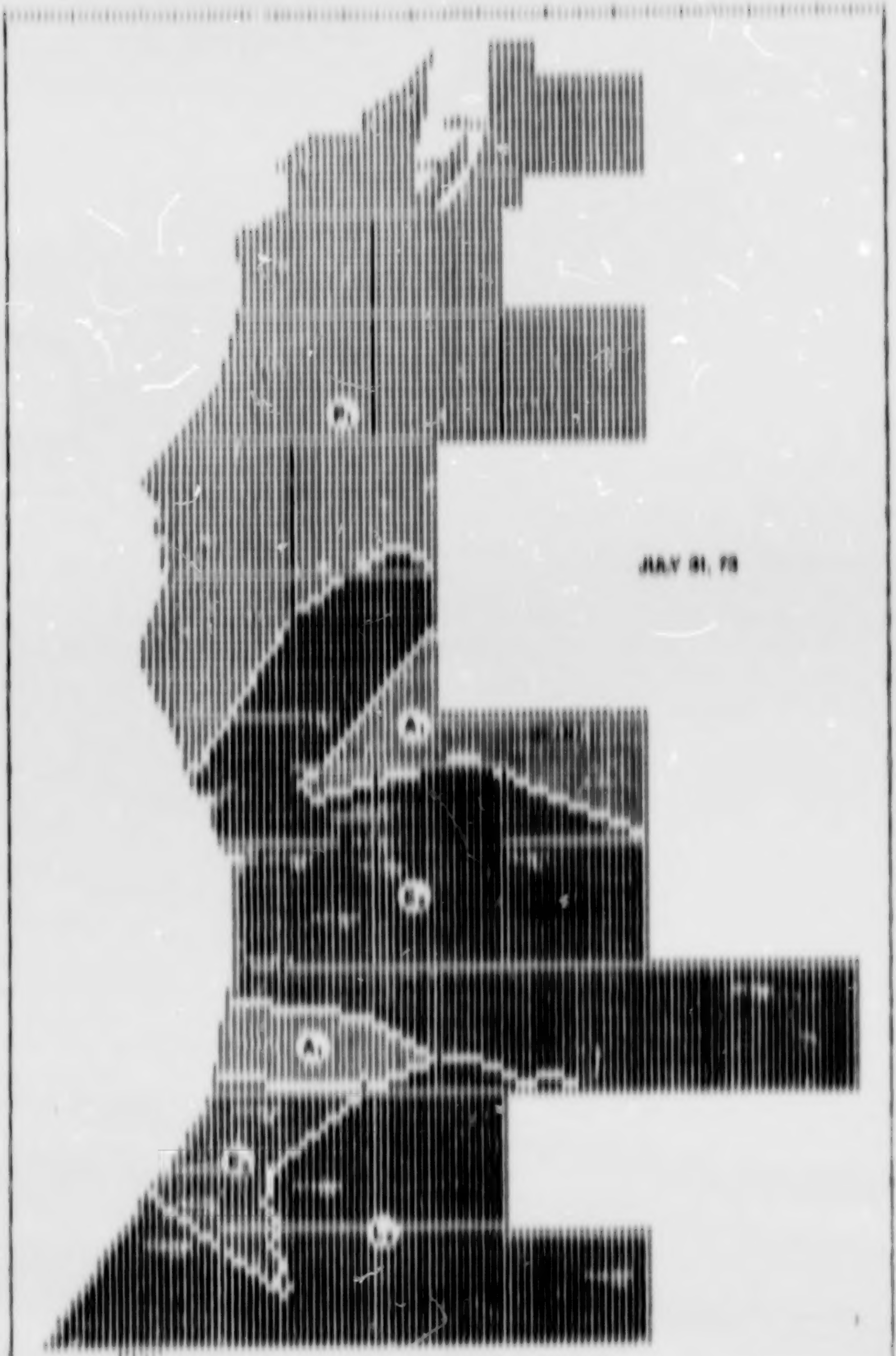

Figure 2. Simulation model-SYMAP output of codling moth, *Laspeyresia pomonella*, phenology in the Michigan fruit belt (P_1 = spring generation pupae, A_1 = spring generation adult, E_2 = summer generation eggs, L_2 = summer generation larvae).

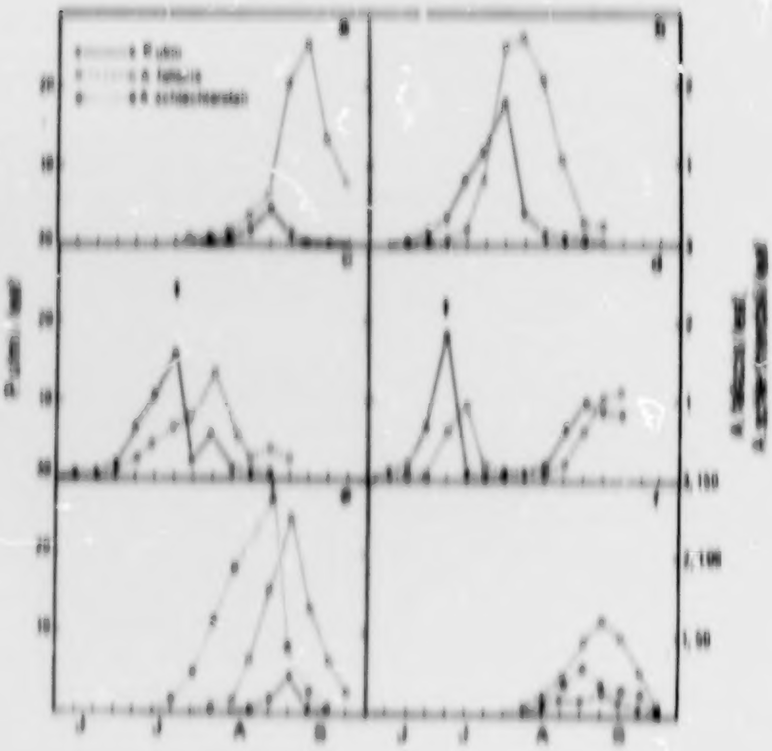

Figure 3. Dynamics of *Amblyseius fallacis* and plant-feeding mites in Michigan apple trees.

is attained (economic threshold is 15 mites per leaf). Figure 3c illustrates how a selective miticide can be used to reduce but not eliminate pest mites and thus change the predator:prey ratio from ineffective to effective. Figure 3d shows the effect of completely eliminating pest mites by using a full strength miticide, the subsequent starvation of predators and a second outbreak of pests (note absence of late-season control or regulation by predators as occurs in Figure 3c). Figure 3e-f demonstrate how apple rust mites may serve as alternate prey for predators and influence control of spider mites by *A. fallacis*. In Figure 3e, apple rust mites build up in apple trees before spider mite populations develop; *A. fallacis* develops on rust mites and becomes well-distributed throughout the tree; a selective chemical which controls rust mites, aphids and leafhoppers is appied as spider mites begin to increase; rust mites are chemically controlled, and predators, which are unaffected by the spray, switch prey and quickly destroy spider mite populations. In Figure 3d a similar condition exists where rust mites are present only at moderate levels; predators are able to enter trees before spider mites but provide complete biological control of both rust mites and spider mite pests without any sprays for rust mites being applied.

The interactions of *A. fallacis*, which overwinters and spends the early spring in the groundcover, with populations of *T. urticae* also can greatly influence biological control in the tree. Extensive sampling and population dynamic studies of these interactions in relation to successful biological control of spider mites have been completed (15). The normal condition in orchards where toxic sprays are not disrupting predators in the groundcover is depicted in Figure 4-5a and 4-5b wherein *A. fallacis* in the groundcover tends to keep two-spotted spider mites at extremely low equilibrium densities, and these populations of predators provide a residual population which may migrate en masse into the tree at any subsequent time when *P. ulmi* begins to increase. Various types of non-selective chemical pesticides can disturb this relationship by effecting the predators. Most often this causes two-spotted mites ~~mites~~ to increase, and they can reach outbreak proportions on weed vegetation under the tree (Figures 4-2, 4-3 and 4-4). When this occurs, it can affect biological control in the tree in two ways. If predators begin to recover from the spray at the time European red mites are beginning to build in the tree, then the high two-spotted spider mite populations occurring on the groundcover serve the predators with a food source and the predators never enter the fruit tree (Figures 4-2 and 4-3). Occasionally, the condition will occur when predators have built to high levels after feeding on the population of *T. urticae* (which have achieved an outbreak level), and control of the mites has occurred at the same time *P. ulmi* is beginning to increase in the tree (Figures 4-4a and 4-4b). The timing of this interaction synchrony is critical, but when it is precise, large numbers of predators will migrate into the fruit tree and biological control of *P. ulmi* will often be effective.

In summary, data from the interaction studies betwen plant-feeding mites and their natural enemies in both the groundcover and tree plots has provided an understanding of how biological control of these pests

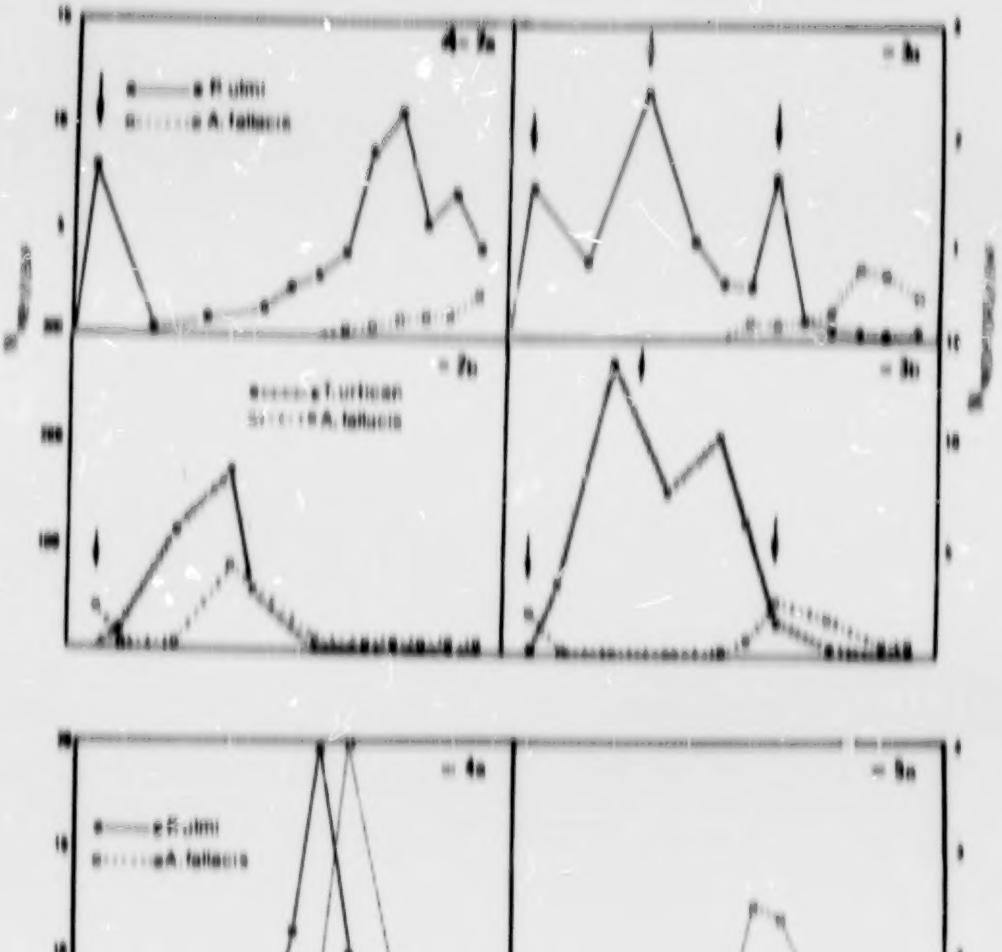

Figure 4. Population dynamics of *P. ulmi*, *T. urticae* and *A. fallacis* in apple tree (a) and ground cover (b) habitats treated with non-selective acaricides (4-2 = 1 direct application, 4-3 = 3 direct applications, 4-4 = 1 drift application and 4-5 = no applications).

is accomplished. Also this information has led to the development of certain manipulative strategies based on the use of selective pesticides or habitat modifications in the orchard which can greatly enhance biological control success and minimize a reliance on chemical control measures.

One interspecific interaction between phytophagous mite species which appears to have significance insofar as mite pest management is concerned is that between *P. ulmi* and *A. schlechtendali*. In addition to the benefits provided by *A. schlechtendali* as an alternate food source for *A. fallacis* (Figure 3e-f), there is evidence that *A. schlechtendali* may inhibit the development of *P. ulmi* by what is believed to be a foliage condition mechanism. Commercial apple orchards where insecticides were used intensively, apple rust mites were common, no major predator populations were present, and spider mites were virtually absent have been observed and recorded. The following is an interpretation of the factors which seemed to create and maintain this situation. According to a 4-year intensive study (Croft, unpublished data), spray records indicated that the pesticides which were being applied in the orchard each year were maximally favorable to the development of apple rust mites. Rust mites were becoming abundant in early season each year in these blocks; however, only a moderate amount of silvering and bronzing was occurring, and this damage was not readily apparent until late season. Apparently, the conditioning of the leaves in early season in advance of the development of *P. ulmi* affected the subsequent reproduction of this spider mite, which is known to be extremely sensitive to small changes in leaf nutrition (20). It was hypothesized that this effect was influencing *P. ulmi* to the extent that over a protracted period of time this spider mite was virtually eliminated as a pest from the orchard. Subsequent laboratory experiments measuring the rate of reproduction by *P. ulmi* were made on leaves which had sustained previous rust mite feeding. Results showed a substantial reduction in *P. ulmi* oviposition even on leaves which had only moderate exposure to rust mites. In addition, release studies of *P. ulmi* onto trees receiving different amounts of previous feeding by *A. schlechtendali* in the field showed a similar effect. Studies conducted subsequently have indicated that it is possible, by spraying insecticides which favor *P. ulmi* as opposed to *A. schlechtendali* to change a block which previously had only a rust mite problem into one where *P. ulmi* was the principal mite pest and vice versa.

Codling Moth

Dynamics studies with this species have principally been confined to an examination of its phenology and behavior in relation to its response to a pheromone trap. In Figure 5, basic features of emergence and oviposition by adult females in relation to the male adult catch in a pheromone trap in unsprayed orchards are graphed on a accumulative heat unit scale (degree-day units) for the two generations which occur in Michigan. As can be seen, there are significant differences in the relationship between curves in each generation. For example, in the spring generation

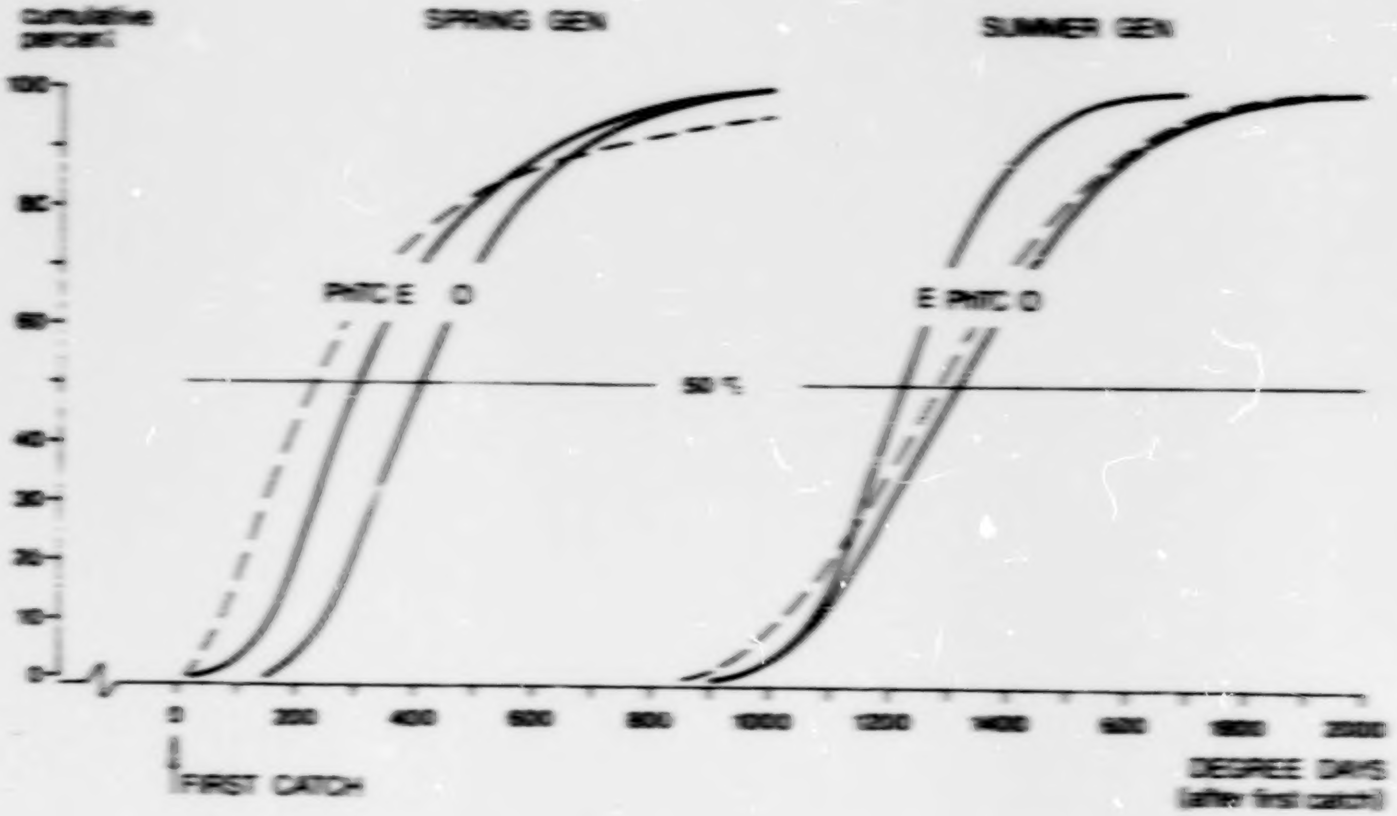

Figure 5. Average relationship between cumulative emergence (E) and oviposition (O) of the codling moth (*Laspeyresia pomonella*) to pheromone trap catch (PHTC) in Michigan.

catch, emergence and oviposition curves increase in almost a parallel fashion, but in the summer populations, catch lags behind emergence and is almost congruent with the oviposition curve. A major factor contributing to these differential responses between generations appears to be related to an increased competition between a larger population of feral females and the pheromone trap in the summer generation. The information presented in Figure 5 has established the basic relationships which had to be determined before a model relating pheromone trap catch to oviposition and ultimately egg hatch could be developed.

Biological Monitoring or Pest Surveys

Phytophagous Mite System

A 5-year study of the dispersion statistics associated with field populations of *P. ulmi* and *A. fallacis* have indicated that both species have a similar distribution as determined by k_c (common k) statistics of the negative binomial distribution and Taylor's (1961) *b* values (Tables 1 and 2). Based on the assumption of a negative binomial distribution, sequential sampling methods have been developed. Using variable precision levels (acceptable variance size in relation to the mean), a program has been developed which uses estimates of predators and prey levels to minimize sampling in the field. As noted, these samples also are used to set the initial conditions for running the predator-prey model. At present these tools are used in a mobile data collection/transmission facility which is testing new implementation techniques in the field.

Codling Moth

For this pest which is very difficult to monitor due to the low densities which occur in commercial orchards and the moth's cryptic behavior, emphasis has been placed on studying the use of the pheromone trap as a sampling tool. In Figure 6 the basic relationships which must be determined before trap catch can be qualitatively interpreted in terms of potential damage are illustrated. Phase I is a study of the relationships between the factors affecting pheromone catch and the activity and density of the male moth population. To predict infestation in each generation from male density of the previous generation further requires an understanding of the population dynamics of each stage during that period (Phase II); Phase III involves predictions made over more than one generation.

At present, research is underway at each of the three levels, but each is a large task in itself. A preliminary study of moth catch and

Table 1. Values of *b* (from Taylor's power law) for *P. ulmi* and *A. fallacis*

Species	Density range (mites/leaf)	*b*	95 percent Confidence interval	Number of trees
P. ulmi[1]	0-177.5	1.594	1.580-1.608	6,057
A. fallacis[2]	0-15.0	1.336	1.323-1.349	3,646
P. ulmi[1]	.2-183.2	1.542	1.500-1.584	147
P. ulmi[2]	.1-90.1	1.450	1.342-1.558	23

[1] Active life stages
[2] All life stages

Table 2. Values of k_c (common k) for *P. ulmi* and *A. fallacis*

Species	Density range (mites/leaf)	k_c	95 percent Confidence interval	Number of trees
P. ulmi[1]	1.2-177.5	1.442	1.297-1.622	3,019
A. fallacis[2]	.2-5.5	.735	.686-.792	2,717
P. ulmi[1]	.2-183.2	1.606	.858-12.3	147
P. ulmi[2]	.1-90.1	.713	.359-55.41	23

[1] Active life stages
[2] All life stages

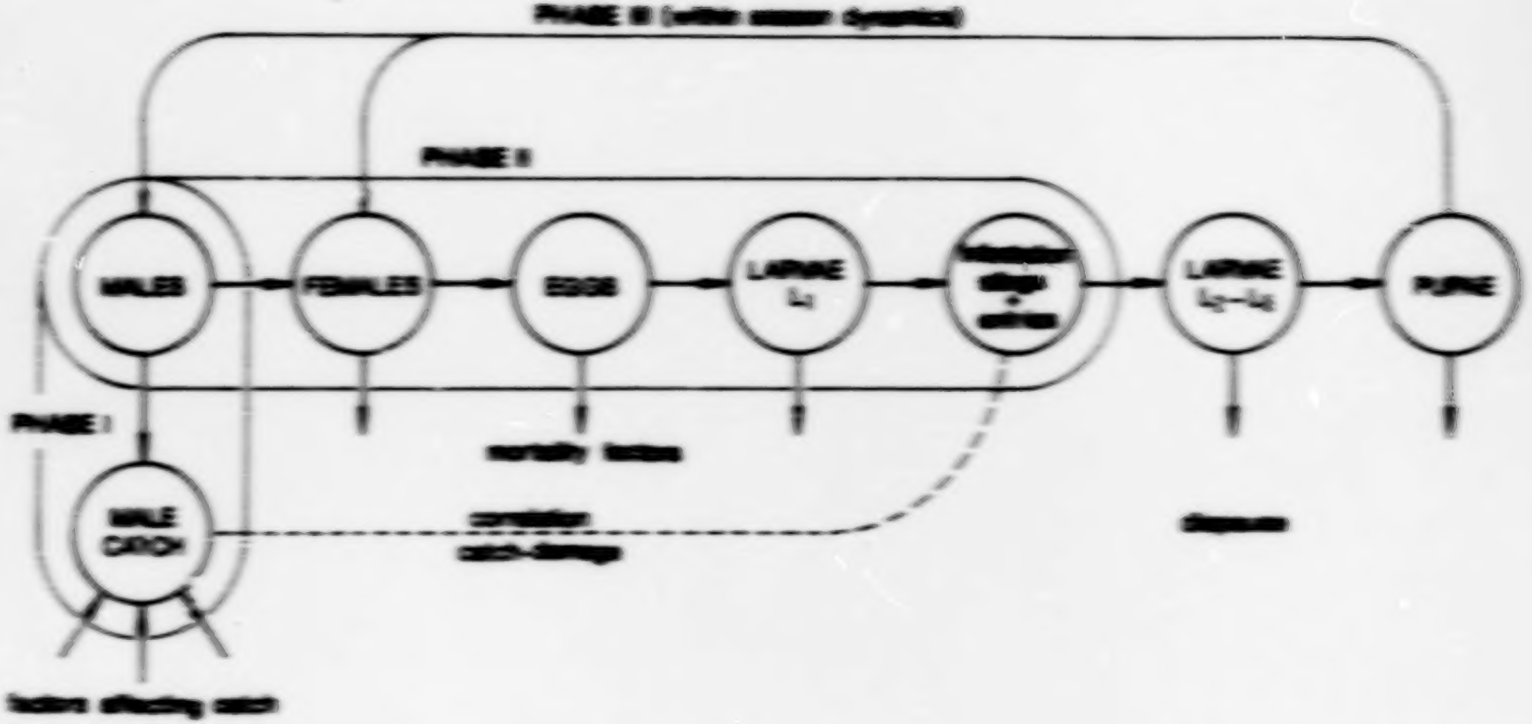
PHASE III (within season dynamics)
PHASE II
PHASE I
MALES
FEMALES
EGGS
LARVAE
L_1
[illegible]
+
[illegible]
LARVAE
L_2-L_6
PUPAE
mortality factors
dispersal
correlation
catch-damage
MALE
CATCH
factors affecting catch

Figure 6. A pheromone catch-damage model for [illegible] [illegible].

infestation after three degree-day periods during the season have shown a good correlation (17), indicating that trap catches do reflect density differences in the orchard. In the future it is anticipated that the variable components affecting the trap-catch to damage relationships can be identified, a model of these relationships can be constructed and the trap can be used more quantitatively to assess populations of moths in the field.

Biological Studies

Phytophagous Mites

In the course of developing the population model for *A. fallacis*, two critical types of biological research were needed. The first was related to the dispersal rates of *A. fallacis* into and out of apple trees. This relation was particularly critical since the rate of migration in early season determines the initial predator-prey ratios established and ultimately determines at what level biological control will occur. Although studies to determine specific rates of predator migration into the tree are still in progress, the general relationship between within-tree populations of prey and predators, predators on the ground and dispersal out of the tree has been ascertained. A "disperal" behavior of *A. fallacis* has been observed in the laboratory, and preliminary studies have evaluated the effects of various parameters, such as temperature, wind speed, starvation conditions and so on, as they influence this response (14).

A second need was data on the functional and numerical response of the predator to its prey at various temperature regimes. In addition, starvation response curves, dispersal response curves, food prey equivalence and other factors affecting predation rates as a function of environmental variables have been assessed and incorporated into the population model for *P. ulmi* and *A. fallacis*.

Codling Moth

In the process of modeling the response of the codling moth to a pheromone trap, an initial step was to determine the variables which affected the response of the male to the trap in nature (Phase I, Figure 6). A component approach wherein male moth catch could be corrected for the influence of such factors as temperature, wind, rain, humidity and so on was undertaken. This phase was constructed as illustrated in Figure 7. First diel periodicity of the male response was established with a battery-operated, timing pheromone trap, which is also a necessary

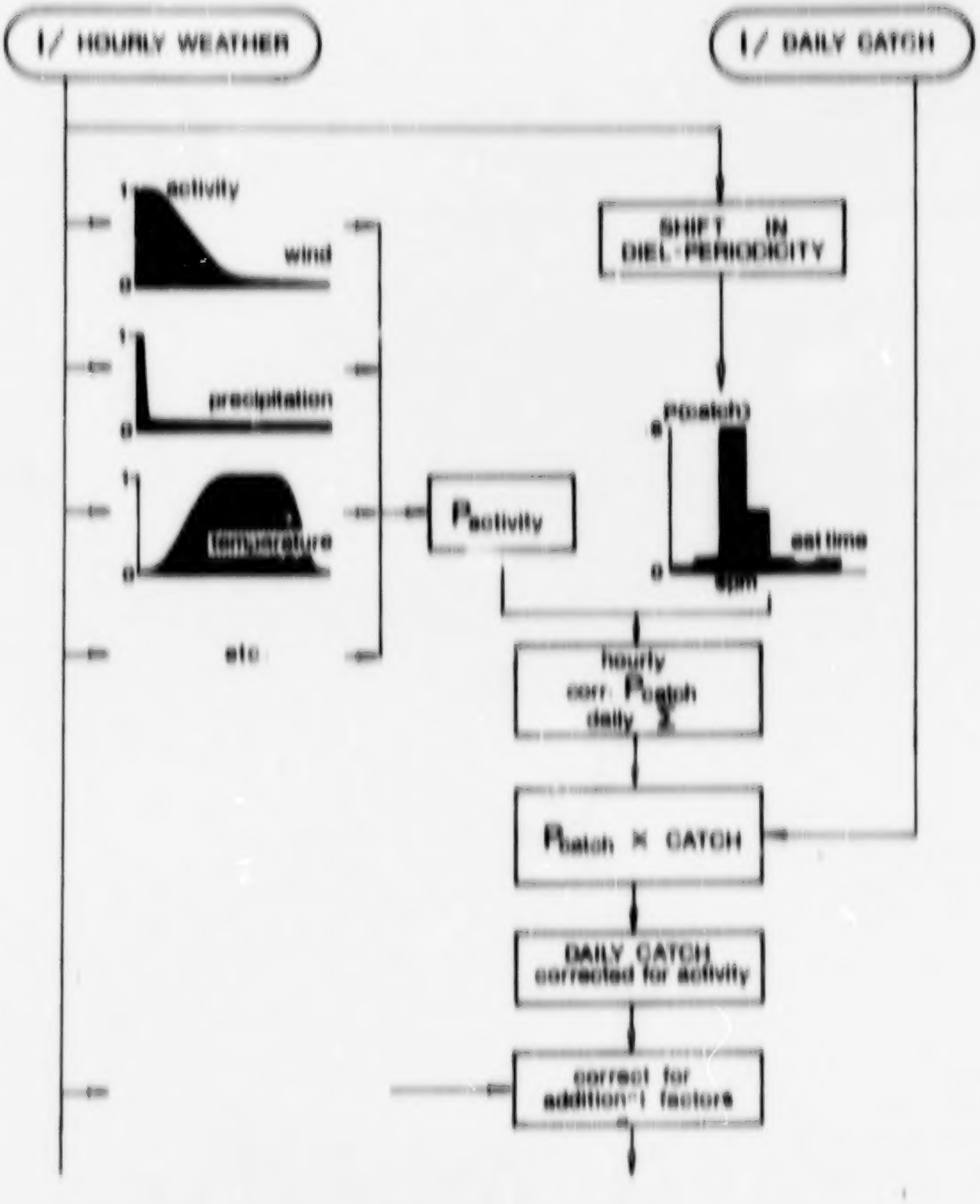
1/ HOURLY WEATHER
1/ DAILY CATCH
1
activity
wind
0
1
precipitation
0
1
temperature
0
etc
SHIFT IN DIEL-PERIODICITY
P(catch)
8
est time
0
8pm
P activity
hourly corr. P catch daily Σ
P catch × CATCH
DAILY CATCH corrected for activity
correct for additional factors

Figure 7. A schematic model of the effects of climatic factors on male codling moth response to a pheromone trap.

tool to study the hourly effect of climatic factors on male activity. This response rhythm is keyed to sunset, and in Michigan, the maximum catches were consistently during the hour following sunset. To correct daily catch for the variable effects of climatic factors, the daily activity rhythm is considered as a probability distribution for catch. The temperature regime before and during sunset can cause certain shifts in this daily rhythm. The onset of flight activity -- as measured by bait traps in this case -- can be delayed by warmer evening temperatures (1). Rain can also condition flight activity; just before the onset of precipitation the author has observed increased flight activity (23). From hourly readings of the climatic variables, individual probabilities for activity can be calculated based on the functional relationship of precipitation, wind, temperature and other factors to activity. Activity then is the product of the individual probabilities and serves to adjust the intrinsic probability for catch as expressed by the distribution of male response.

Management Studies on Plant-Feeding Mites

Background

Much research has gone into studying chemical insecticides used in orchard pest management in relation to their effects on *Amblyseius fallacis* (4) and developing spray programs for the entire complex of pests in apple orchards selective to *A. fallacis* (2). These have included routine screening evaluations (19), documentation studies of OP and carbaryl resistance in these mites (5,7,9), genetics studies on the basis of organophosphate resistance (5), cross resistance studies (5,11) and release programs wherein attempts to utilize insecticide-resistant strains of this effective mite predator were evaluated (7).

Studies of groundcover populations of *Amblyseius fallacis* and its prey in relation to weed management have been carried out at several levels of investigation. Sampling procedures for studying the dynamics of groundcover inhabiting population of *Amblyseius fallacis* have been developed; two methods, including a timed vegetation analysis and an apple water sprout sample, showed good correlation with absolute density estimates which are more difficult to collect (15). Effective within-tree predator:prey ratios for biological control of the European red mite are very closely correlated with the numerical build-up of predator populations in groundcover habitats just before their dispersal into fruit trees. Strategies of groundcover, prey and alternate food manipulations have been developed, and they demonstrate how proper groundcover control can enhance within-tree pest management. Efforts to manipulate groundcover microhabitat weather, food conditions and plant distribution so as to encourage earlier and larger dispersal of mites at the proper time have been able to affect decreases in the dispersal of predators and, consequently, a reduction in biological control effectiveness within apple trees. Overwintering studies have demonstrated that there is a positive correlation between amount of groundcover vegetation (presumably related to the number of overwintering sites) and the overwintering survival of the predator, *Amblyseius fallacis*. Weed science personnel have developed various herbicide treatments with respect to plant distribution (strip spraying) and plant conditioning with herbicide treatments (hollowstem effect) which greatly enhance the overwintering survival without affecting requirements for effective weed control during the subsequent growing season.

Implementation

Each of the specific research phases discussed previously contributes information towards understanding, modeling and ultimately managing plant-feeding mites and the codling moth. Of course, they also contribute to the total apple pest management system. These control systems, however, must be reduced to a simplified form for extension application. Our final discussion focuses on several new approaches being taken to make these types of pest management programs more operationally available to growers in the field.

In Figure 8, the personnel and information flows associated with fruit pest management are depicted beginning at the research base where programs are initially developed and experimentally evaluated and extending to the field level where various paraprofessional pest managers apply the science. At present, a computer-based data access/delivery system (PMEX), comprised of a telecommunication network, couples a central computer system dedicated to pest management with remote site teletype terminals located in extension agent offices. This system, in essence, is identical to Figure 8 insofar as the information flows are concerned. Several information types are currently collected from the field, summarized or interpreted in the computer and redelivered in a more meaningful form to the user. They include model outputs such as those previously described for the phytophagous mites and the codling moth; weather data and forecasts; biological data sets (such as pheromone trap data); general summaries on insect activity; and other tasks related to traditional extension activities. This system operates on an on-line basis insofar as delivering model outputs; with respect to other information types, communication flows are delivered more rapidly and made available to a larger number of users as compared to traditional means of delivery.

The system described above has been designed to provide enhanced processing capability at the county agent level. A natural extension is to consider automation at the orchard level. To evaluate this possibility a prototype mobile monitoring and educational unit was put in the field last summer. The unit consisted of a van containing a programable calculator (for models and statistical analyses), a data terminal (for calculator output and interaction with remote computers), a slide-tape projector (for audio-visual educational material) and a battery power supply (to permit operation in the orchard itself).

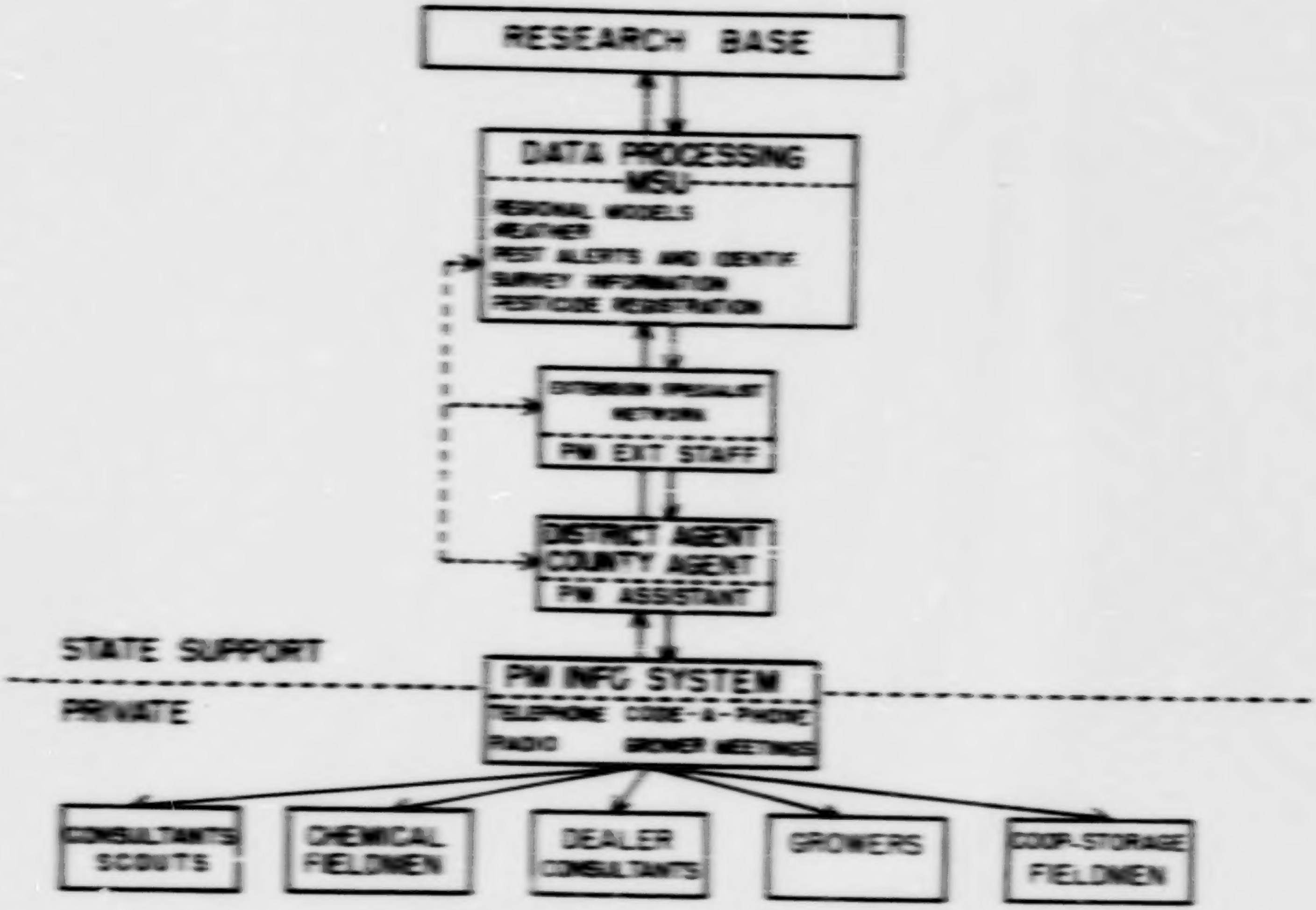
RESEARCH BASE
DATA PROCESSING
MSU
REGIONAL MODELS
WEATHER
PEST ALERTS AND IDENTIF
SURVEY INFORMATION
PESTICIDE REGISTRATION
EXTENSION SPECIALIST
NETWORK
PM EXT STAFF
DISTRICT AGENT
COUNTY AGENT
PM ASSISTANT
STATE SUPPORT
PRIVATE
PM INFO SYSTEM
TELEPHONE CODE-A-PHONE
RADIO GROWER MEETINGS
CONSULTANTS
SCOUTS
CHEMICAL
FIELDMEN
DEALER
CONSULTANTS
GROWERS
COOP-STORAGE
FIELDMEN

Figure 8. An information network for pest management in Michigan.

Although the hardware is flexible enough to support a variety of pest programs the van was operated last summer as a mobile mite-counting service. On grower request, the van was dispatched to potentially mite-infested orchards. Leaf samples were then taken and counted using a sequential sampling alogrithm programed on the calculator to optimize manpower usage. Both predatory (beneficial) and phytophagous (pest) mites were counted. When the calculator had sufficient data, it generated a control recommendation based on a regression management model. This recommendation was printed out at the data terminal.

Concurrently with these operations the grower (if present) was viewing a 30-minute slide tape presentation on integrated mite control. Pictures of pest and beneficial mites were shown along with descriptions of their life histories. The lethality to predators of various pesticides was discussed, and the grower was told how an integrated spray schedule would be devised. The importance of mite counts was also demonstrated, and specific grower questions were answered by the mite van personnel.

At the end of the day, with the aid of the data terminal, the staff of the van contracted the Michigan State University central computer via a long distance telephone call. At this time the results of the day's counts (stored on cassette tape) could be sent to the computer. More sophisticated models could then be used to validate any borderline regression model recommendations. The data thus became available to researchers or extension personnel using the PMEX system.

Summary

The basic research elements for developing an on-line pest management system for two prototype apple pests have been briefly described in this presentation, and several experimental programs for implementing these systems have been discussed. While it is too early to completely assess the usefulness of the system-science approach or the use of predictive models in applied entomology, the two systems for fruit pests described provide valuable insights into its potential. First, models and the system-science logic or methodological approach undoubtedly improve the design of a pest management research program. Second, simple models such as those described can play a useful role in decisionmaking in the field as long as they are carefully constructed, properly validated and their limitations and proper role understood. One limiting factor in making long-term predictions with these tools is related to our limited ability to predict the weather. However, with the on-line capabilities and a real-time delivery system such as the one discussed, up-dates in models based on biological inputs and short-term weather forecasts can be rapidly evaluated. Subsequently, redissemination of model outputs to the user provides an extension system which can rapidly respond to grower needs and changing biological conditions at the site of management.

Acknowledgment

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Cotton Pest Management

INSECT PEST MANAGEMENT ON COTTON IN THE UNITED STATES

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Cotton is produced on about 11 to 13 million acres of land each year (about 5 million hectares) in the United States. About 99 percent of the cotton produced represents several varieties of the upland species, *Gossypium hirsutum*, while the remainder, approximately 1 percent, is the long-fibered Pima cotton, *G. barbadense*. The average yield of *G. hirsutum* in the United States is a little more than 1 bale of lint per acre (about 500 kg per hectare). In some irrigated areas, for example, Arizona and California, the average is about 2 bales per acre. A bale weighs about 500 pounds. In a good production year, restricted areas such as the Imperial Valley of California average as high as 3 1/2 bales per acre (1,700-1,800 kg per hectare) with some fields producing in excess of 5 bales.

Estimates of crop losses caused by insects are notoriously variable and poorly documented. The average annual loss to insects for the period 1951 to 1960 was calculated to be about 19 percent of the potential crop. Although all the plant parts may be attacked, the most serious pests attack primarily the fruiting portions -- squares, blooms and bolls -- reducing both quantity and quality of the harvested lint and seed. It has been calculated that nearly 80 percent of the losses attributable to insect pests was caused by species that attacked the fruiting forms (14). Clearly such losses year after year are intolerable and strongly suggest that prevailing cotton protection practices are less than ideal.

After the discovery and widespread adoption of the synthetic organic insecticides starting in the late 1940's, insect pest control on cotton relied almost completely on the use of insecticides. Despite their effectiveness and the production stability provided by them, the problems associated with their heavy use (insecticide resistance, lack of selectivity resulting in secondary pest problems, ecosystem contamination and so on) and the continuing significant production losses due to pests caused a reappraisal of plant protection practices some years ago. This reappraisal resulted in increased acceptance of the philosophy which is now known as integrated control or insect pest management.

Insect Pests

Everywhere cotton is grown in the United States there are at least one or more key pests whose population must be managed or controlled each production season if cotton is to be grown profitably. Obviously in the case of such key pests, natural controls, including insect natural enemies, are inadequate to suppress populations below economic thresholds. It is precisely on such key pests that integrated pest management should be focused initially. It is their suppression without ecosystem disruption that provides the key to pest management programs in the cotton ecosystem (16). Present control technology for most key pests rests largely on insecticides, repeated applications often being made at frequent intervals. This creates serious upsets and imbalances in the arthropod complex, and secondary pest outbreaks often follow.

In general, there are three major cotton-producing regions in the United States, and each has a somewhat different complex of key pests: (1) the irrigated deserts of the far West where the key pests are the pink bollworm, lygus bugs and the bollworm, *Heliothis zea*; (2) the semi-arid regions of the southwestern United States where the boll weevil, fleahopper, bollworm and tobacco budworm, *H. virescens*, are the key pests; and (3) the humid regions of the mid-southern and southeastern United States where the boll weevil, plant bug, bollworm and tobacco budworm are the key pests (2).

There are also large numbers of occasional and potential pests (about 100 species). The occasional pests reach population levels infrequently, at which time economic damage may result. Some of these species become problems almost exclusively when their insect natural enemies are killed by insecticidal treatments applied for control of key pests. The potential pests seldom reach damaging population levels, because they are under constant population regulation -- often by environmental factors. Care must be taken, however, that changes in agronomic practices in cotton production (such as a new variety) do not allow large population increases of occasional and potential pests to become serious, consistent pests (16).

The Cotton Ecosystem

The foundation of insect pest management is a detailed knowledge of the crop ecosystem. Despite its apparent simplicity, it is a remarkably complex ecological unit with a multitude of interacting factors. It is not a unit in isolation but is part of an ecological system which includes associated agricultural fields of various types, woods, streams, weedy and uncultivated areas and many more. The major components within the fields include the cotton plants, weeds, the soil and its biota; overall conditioning of the physical and chemical environment; pest species with their natural mortality factors, including disease and beneficial insects;

and the overall conditioning of man, including his management of this system. In reality, therefore, the ecosystem is very complex and probably will never be understood completely. Furthermore, what is learned about one cotton system may be indicative but is not directly applicable to another area. Each major cotton production area differs to varying degrees, because different cotton varieties are grown under different management systems. Also, there may be distinct differences in the surrounding physical and crop environments in the different regions. In fact, neighboring fields in the same region vary to some degree for the same general reasons. In recent years, entomologists in the United States have progressed remarkably in their knowledge of the cotton ecosystem and the interactions therein.

Cotton plants follow a consistent and predictable pattern of growth. The pattern varies somewhat according to variety and environmental conditions under which the plant is grown but may be defined for each situation. The maximum boll-carrying capacity is genetically determined, but final yields are strongly influenced by the physiological capacity of the plant as modified by temperature, day length, soil fertility, moisture and cultural practices, as well as by insects and other plant pests. Routine, periodic plant examination by the cotton grower can provide a clear evaluation of the progress of fruiting and crop maturity.

The growth and fruiting characteristics of the cotton plant are very important to pest management programs. The presence of vegetative and reproductive fruiting branches and the indeterminate growth and natural shedding of squares and small bolls is well known. Flowering is progressive; shedding is very light in the early fruiting stage of the plant but increases with time (9). Boll retention likewise is excellent early in the season but declines as the season progresses. Over a season, nearly two-thirds of the squares fail to produce bolls. This occurs in the absence of any pest species which may affect the fruiting pattern. Thus, insect-produced square and small-boll shed may have little effect on yield if less than the normal shed of the plant (18). The ability of the plant to compensate and retain fruit to its physiological capacity is exemplified further by the fact that stands of 25,000 to 75,000 plants per acre produce about the same yield per acre under comparable growing conditions (4). The early squares appearing from about June 1 to July 10 result in flowers on about June 25 to August. These contribute the most to yield. Consequently, this is a critical period during which squares should be protected from excessive loss that may be inflicted by insect pests.

Host Plant Resistance

Many strains of *Gossypium hirsutum* have been developed which incorporate desirable characteristics, such as quality and quantity of fiber produced, early fruiting and early crop maturity. Most of these strains have been developed without consideration of possible varietal relationship to pest problems. Recently, however, research has been sharply accelerated by teams, including entomologists and other crop production and protection personnel, on development of cotton strains resistant or tolerant to attack by important pest species.

Beneficial Insect Fauna

Even though cotton is grown normally on an annual basis, cotton fields contain a varied and complex entomophagous fauna. Indeed, it would not long be possible to produce cotton crops economically without the regulatory impact of parasitic and predaceous species on the pest complex. In many areas, heavy use of chemical pesticides virtually eliminates these natural controls. As a result, there is often a tremendous resurgence of primary target pest species and the unleashing of secondary pests following the use of pesticides. The disruption of insect natural enemies is caused primarily by direct mortality but can also take place through disruption of their food chains (16). More than 600 species of predators and parasites have been found in cotton in the United States, where they normally do an effective job in keeping most insect pests below crop-damaging numbers (23). Unfortunately, not all pests of cotton are regularly subjected to such desirable population regulation by beneficial insects. Parasitism and predation of the boll weevil and pink bollworm, for example, are less than adequate. Predation on lygus bugs in the irrigated western United States is seldom sufficient by itself to keep populations below economic levels. This is why the boll weevil, pink bollworm and lygus bugs are all considered key pests, whereas the potentially highly destructive bollworm (*Heliothis*) complex is considered less of a threat unless coupled with ecological disturbances as may be caused by insecticide application (16). A single application of insecticide to cotton is at times all that is required to reduce effectiveness of natural enemies to the point where secondary pest outbreaks can occur (14).

As in other areas of the world, crop protection specialists presently are searching for methods that conserve natural enemies. One way to accomplish this is by minimizing the use of insecticides or timing their applications so as to cause minimum disruption of the natural enemy complex. In addition, there is an intensive search for insecticides which are physiologically selective, sparing most beneficial species, or those that can be used at a sufficiently low dosage rate that selectivity results.

In the development of integrated pest management on cotton, an inventory as complete as possible should be made of the beneficial species. Population census and periodic sampling also provide knowledge on the seasonal activity of cotton pests and their natural enemies. Once sufficient data has been obtained, definite relationships may be established between pests and natural enemy numbers (18). In general, there are two ways of utilizing natural enemies of cotton pests in integrated pest management programs: (1) by means of a pest management system that preserves and augments naturally existing populations of predators and parasites and (2) by mass rearing of natural enemies for release as nuclei for further reproduction in the field at the expense of a given pest or pests or, what is more desirable, for release in large numbers as a population regulator. There are, in addition, at least three ways of preserving natural enemies of importance in the cotton ecosystem: (1) knowledge of the effects of different pesticides on the most important beneficial species, through experimentation, which permits the selection of pesticides not only according to their effect on the target pest concerned but also according to their ability to leave alive as many beneficial forms as possible; (2) restrictions on the use of broad-spectrum insecticides to cases of absolute need. This should be carefully controlled by entomologists responsible for technical assistance, backed by regulatory cultural practices and adjusted to the ecology and needs of each locality; and (3) development of alternative, non-insecticidal methods of pest control which can aid greatly in the preservation of natural enemies (16).

Insect Pathogens

Epizootics of naturally occurring insect diseases are sometimes observed in the cotton fields. In fact, in many areas of the cotton belt, producers commonly depend on virus diseases of the cabbage looper for control of this pest. Insect diseases are important entities in the regulation of abundance of many insect pest species. Besides causing outright death, insect pathogens may be more subtle in their effect and may interfere with insect development and reproduction, lower insect resistance to attack by parasites, predators and other pathogens or even influence the susceptibility of insects to control by chemical pesticides. At the current time in the United States, *Bacillus thuringiensis* and the nuclear polyhedrosis viruses of the bollworm, cabbage looper and beet armyworm are of the most interest to researchers and commercial firms (16). *Bacillus* is already registered for use on cotton and is available commercially, although used in practice quite sparingly on cotton. The nuclear polyhedrosis virus of *Heliothis* has been registered for experimental use and widely tested. Results have been erratic to date, but its continued use is dependent upon protocols for registration which have yet to be established by the United States Environmental Protection Agency (EPA). Progress in evaluating and developing the use of insect diseases has been slow. It is expected that it will continue to be slow until protocols for registration are established by the EPA (11). Most entomologists, however, expect that manipulation of insect diseases will play a significant role in insect pest management programs in future years.

Chemical Control

Nearly 50 percent of the insecticides applied to agricultural crops in the United States are used on cotton (10, 15). Chemical pesticides are useful and powerful tools for the management of pest populations. Many are effective, dependable, economical and adaptable for use in a wide variety of situations. In some cases it is the only known control for many of our most important pests on cotton. No other tool lends itself with such comparative ease to manipulation, and none can be brought to bear so quickly on outbreak populations. It is recognized that pesticide chemicals have been and will continue to be an essential part of cotton production, but current practices in pesticide use have not always been sound, either in terms of cotton production or from the standpoint of human health and environmental quality.

The proper use of pesticide chemicals depends mostly on a continuing program of research and education. Each use should be judged on the basis of the potential positive values to be achieved, as weighed against the possible negative values, such as those from residues on the harvested crop, occupational hazards to people, hazards to pollinating and other beneficial insects, harmful effects on wildlife and increases in environmental pollution. We have already mentioned the essentiality of insecticides in cotton production, and we have also mentioned very superficially some of the problems which may follow their use.

Another serious problem occurring in the United States has been the development of resistance to the insecticides used on cotton. All the most important arthropod pests of cotton in the United States have developed resistance to one or more pesticides. You will note that most cases of resistance occur in the organochlorine componds, but a number of species of mites and insects are now known to have developed resistance to the organophosphorus and carbamate-type insecticides.

Before insecticides can be used in rational programs, it is essential to understand the relationship between pest infestation levels and crop loss. These are commonly called "economic thresholds," the maximum pest population that can be tolerated at a particular time and place without a resultant economic crop loss. It is important to recognize that economic crop loss depends not only on the numbers of pests present but also upon the plant reaction to the attack. In addition to considering pest abundance, age structure and duration of attack, the stage of the plant growth when attacked, and especially the surplus amounts of fruits being produced by the plants, must not be overlooked. Because of the variability in the effects of factors causing economic losses, long-term experiments are generally required to establish economic losses, long-term experiments are generally required to establish economic thresholds in relation to intensity of attack. These are difficult to develop and may take a number of years of carefully designed research programs. When economic thresholds have been carefully established, unnecessary applications of insecticides with the concomitant problems accruing to them can be avoided, and also, unnecessary losses to pests can be avoided. Thus, much of the guesswork is eliminated from insecticide application.

Influence of Agronomic Practices

Any modification in prevailing practices in cotton production may create changes, sometimes subtle, in the plant and the environment. The attractiveness and suitability of the plant and the environment to the pest may be altered and sometimes this may aggravate or ameliorate certain pest problems or even create new ones. Modification in time of application and amounts of irrigation or fertilization, use of different cotton varieties, plant and row spacing, cultivation practices and time of planting and crop maturity may all have an impact on pests or beneficial species (16). Some of these modifications are designed especially to give cultural control of certain pests. In some cases these provide the first line of defense against pest species, and utilization of other suppressive measures, for example, insecticides, is only supplementary.

Cultural Controls

There are many cultural practices useful in reducing cotton pest problems. These include an area-wide uniform planting date, a cotton-free period, early crop maturity and harvest, destruction of infested bolls, destruction of alternate hosts, early and uniform stalk destruction, use of trap crops and more (14).

The present cultural program of the pink bollworm in Texas provides an excellent example of a successful cultural program. This evolved from a series of studies which provided a very thorough understanding of the ecology and biology of this species (3). Although these practices are well known, they include (1) defoliating or desiccating the mature crop to cause all bolls to open at nearly the same time; (2) harvesting the crop early, shredding stalks and plowing under crop remnants immediately; (3) irrigating before planting in desert areas if water is available; and (4) planting the new cotton crop during a designated planting period which allows for maximum suicidal emergence of overwintering moths (that is, moths emerge and die before cotton fruit is available for oviposition). In some areas of the United States, control measures, such as the pink bollworm cultural control program in Texas, are enforced by law.

Habitat Management

In the case of the boll weevil, it has been determined that it is important to obtain maximum reduction of potential overwintering adults. The pre-hibernating weevils are killed by insecticide before they leave the cotton fields for hibernation in nearby woody or brushy sites. This program has proved highly effective in reducing boll weevil numbers the following season, and thus, there is less adverse impact on the arthropod natural enemies of the bollworm and tobacco budworm as less insecticide is necessary for boll weevil control. In some years this combination of practices applied on an area-wide basis has so reduced boll weevil numbers that they have not been able to attain economic thresholds during the subsequent growing season. An important result has been conservation of insect natural enemies so that outbreaks of bollworm and tobacco budworm have not occurred (1, 6, 7).

Renewed attention is being given by research entomologists to other cultural controls. Dr. Vernon Stern in California has been spending considerable time on the effect of ecosystem diversity upon cotton pest problems. The lygus bug, *Lygus hesperus*, is a key pest of cotton in California. This insect prefers alfalfa to cotton, and when the alfalfa fields are cut, the lygus bugs leave in vast numbers, frequently appearing quickly in cotton fields in populations that far exceed economic thresholds. Since they cause little damage to alfalfa hay fields, Stern has demonstrated that it is possible to keep them in the alfalfa by cutting the field in alternate strips rather than completely cutting the entire field at one time. The adult lygus bugs move to the uncut strips rather than flying to nearby cotton fields (19). He also demonstrated that interplanting 20-foot-wide strips of alfalfa through the cotton fields concentrated the lygus bugs in the alfalfa strips and kept the surrounding cotton virtually free of lygus bug infestation (20). Although ecosystem diversity or habitat management is a potentially useful technique in managing cotton pests, we cannot assume that maximum diversity in an area is always desirable. Each situation must be carefully studied for its own merits, as we cannot generalize regarding the effect on potential pest problems.

Potential New Techniques for Managing Insect Pest Problems on Cotton

Various types of insect traps are used in insect pest management programs. Fluorescent ultraviolet (black light) lamps are useful in fixing the time of appearance and seasonal abundance of important insect pests. These are not used as a control measure but are useful in evaluation of possible control needs. These light traps catch certain types of moths, and the information resulting alerts growers and entomologists to moth activity in the fields and possibly to potential size of infestation. In this way, then, field sampling can be intensified at the proper times and control methods used with greater precision.

In recent years, the use of sex pheromones has proved useful in pest management programs. The sex pheromone of the pink bollworm, for example, is very useful in survey and detection of this pest. Recently, it has been shown that the sex pheromone can be used to determine the time to initiate insecticide treatments for this insect (21). Although research is not completed on this technique yet, it has been demonstrated that insecticide applications can be timed much better by use of the sex pheromone traps, and over a season it has been possible to reduce the number of insecticide applications by three to five.

At this time a new pink bollworm population suppression technique is under investigation. With this method, the sex pheromone is continuously evaporated in the air of the cotton fields throughout the cotton production season (17). The subsequent disruption of pre-mating pheromonal communication between males and females of the pink bollworm resulted in a reduction of larval boll infestation comparable to that provided by commercial insecticide applications which, at this time, are necessary at 5- to 7-day intervals in parts of southern California and Arizona. It is believed that the feasibility of this technique has been demonstrated, but several technical problems must be overcome before it can be adopted for farmer use.

The pheromone of the boll weevil acts as an aggregating signal for both sexes (12). The synthetic preparation of this material, called grandlure, is used now in restricted areas for detecting low level infestations, particularly early in the season. It would seem highly likely that the use of grandlure when integrated with other suppression techniques, such as short-season cottons, early stalk destruction and so on, may hold populations below economic thresholds (5, 13, 22). Some entomologists believe that these new techniques, properly integrated, are so promising that there is hope for eradicating this pest from the United States (8). Indeed, preliminary programs are underway to this end. Many other entomologists believe that eradication is too optimistic over such a large area (approximately 10 million acres), but it does appear that the pheromone, when properly used with other techniques, may make integrated pest management programs feasible with a concomitant reduction in insecticide load in the cotton environment.

Field Evaluation

Specially trained personnel, often referred to as pest management specialists, are increasingly used to make insect population counts in the fields. In addition to pest species, beneficial insect populations can be evaluated and full advantage taken of those that are present. Furthermore, plant growth and fruit development, as well as damage, can be measured at regular intervals. This information, plus use of previously determined economic thresholds, takes the guesswork out of insecticide applications and, while eliminating unnecessary treatments, improves the timing of those control measures necessary. It is anticipated that cotton farmers will employ increasing numbers of professional pest management specialists for their expertise. Increasingly sophisticated information is becoming available for application of pest management strategies. The professional pest management entomologist, employed solely for his skill and experience, will advise farmers in their decisionmaking process (16). Without such skilled advisors, pest control measures may not be applied at the right time or in the right way, and programs will fail. Although many pages of scientific literature have been published to provide information on all of these matters, pest control for the average farmer is still more of an art than a science. Certainly more research is needed, both applied and fundamental, and the results, when coupled with strong educational programs for assisting cotton producers and their pest management advisors in the solution of the problems in the field, should lead us to the goal of integrated pest management on cotton. In fact, much information is already available initiate insect pest management programs in the field. Some programs are already underway. Goals are set, but only a start has been made.

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ASSESSMENT OF THE ROLE OF PEST-RESISTANT PLANT VARIETIES WITH A REDUCED USE OF PESTICIDES

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The protection of plants from pests has become an essential factor in the continuing expansion of agricultural production. Therefore, constant attention should be devoted to perfecting basic methods of plant protection by improving the traditional methods and developing new ones which are more efficient in pest control and less harmful to man and the environment.

Among nonchemical methods, the most remarkable and successful appears to be the use of pest-resistant varieties of agricultural crops because of their effectiveness, reliability, economic efficiency and protracted action.

Pest-resistant varieties are cultivated at the present time which have excellent nutritional and taste properties. Among these are wheat varieties resistant to *Mayetiola destructor*, Cephidae, aphids and other pests and potatoes of the varieties Kennenbeck and Bint'ye which are relatively resistant to the Colorado potato beetle. These potatoes also taste good. The same applies also to the sweet and common varieties of corn resistant to *Pyrausta nubilalis, Heliothis armigera* and many others.

It is now generally recognized that utilisation of pest- and disease-resistant varieties is a major basis of any integrated system of plant protection. Cultivation of pest-resistant varieties reduces the multiplication and spread of pest insects and plant diseases. This makes the environment in the fields much healthier. As a result, harvest losses from injurious organisms are considerably reduced.

Furthermore, all this considerably reduces the need for pesticides so that, in many cases, it is possible to do without them entirely. It is important to realise that the use of even partially pest-resistant varieties contributes to controlling mass reproduction and spread of injurious organisms and reduces the need for chemicals on the crops. The latter fact is of particular importance in view of the growing necessity to implement measures for the protection of the environment and food from pollution by insecticides.

It appears expedient, in this context, to try to assess quantitatively how the use of a moderately pest-resistant variety reduces the need to use pesticides for its protection. Numerous researchers, including Soviet scientists, have shown that the physiological conditions of pests deteriorate as they feed on pest-resistant plants, which, in the final analysis, reduces their reproductive potential. It is known that the lower the reproductive potential, the smaller the portion of the population that must be destroyed to keep it at a low steady level or reduce it to an even lower level of abundance. Also, smaller amounts of pesticide may be required to maintain pest suppression below damaging levels.

Chapman's widely known formula (Figure 1) may be used to make an approximate quantitative assessment. The formula gives the relation between the fertility of the pest, the sex ratio and the so-called "resistance of the environment." The latter factor Chapman understood to be that percentage of individuals of a population in each pest generation which is destroyed by the effects of various negative environmental factors and through which the population is held, theoretically, at a steady level of abundance, without increasing or decreasing. If only the effect of the insecticide is evaluated and all the other factors are assumed to be constant, then this formula makes it possible to calculate the "critical effectiveness" of the insecticide, the effectiveness at which the population will be kept at the steady level of abundance, for example, for a particular reproductive potential (the number of female offspring in the progeny of one female). For instance, to prevent the population of one female). For instance, to prevent the population of a pest whose biotic potential equals 40 from increasing, the insecticide must destroy in each generation 97.5 percent of the individuals; and if the potential is 20, 10 or 5, the percentage to be destroyed must be, respectively, 95, 90 or 80. It is seen that with a considerable reduction in the biotic potential (from 40 to 5) the critical effectiveness does not diminish so noticeably--for example, only from 97 percent to 80 percent--and the decrease in reproductive potential within such limits is not likely to correspondingly affect a decrease in pesticide use. Such would be correct if there were a linear dependence between the dose of pesticide and the mortality of the pest.

By juxtaposing the changes of critical effectiveness and the changes in pesticide doses we can show, however, that the situation is not that acute after all. Figure 2 shows schematically the dependence between the doses required to kill a hypothetical pest at different values of biotic potential and values of "critical effectiveness" corresponding to the latter. Since the relation between effect and dose depends to a great extent upon the type of effect produced by the poison, the figure shows the "dose-effect" curves for pesticides with different slopes of activity (regression factor). It is known that, as a rule, insecticides with a swift and acute effect, more than 1 on the curve, have a higher regression factor than insecticides with a slower action, for example, 5. Under field conditions, because of the effect of various factors, the regression factor usually decreases, frequently attaining levels lower than 1. This is why the types of effect produced by various

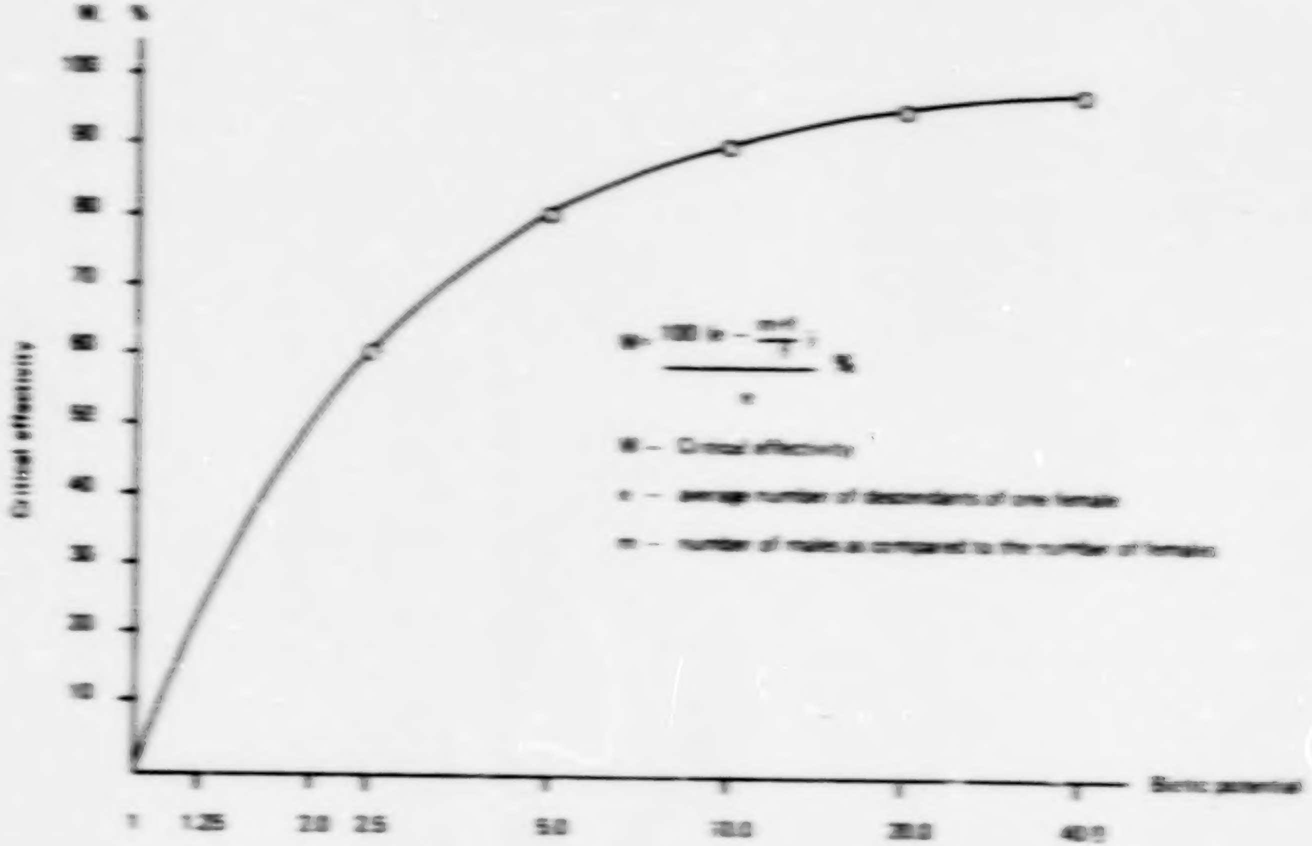

Figure 1. Relation between critical effectivity and biotic potential.

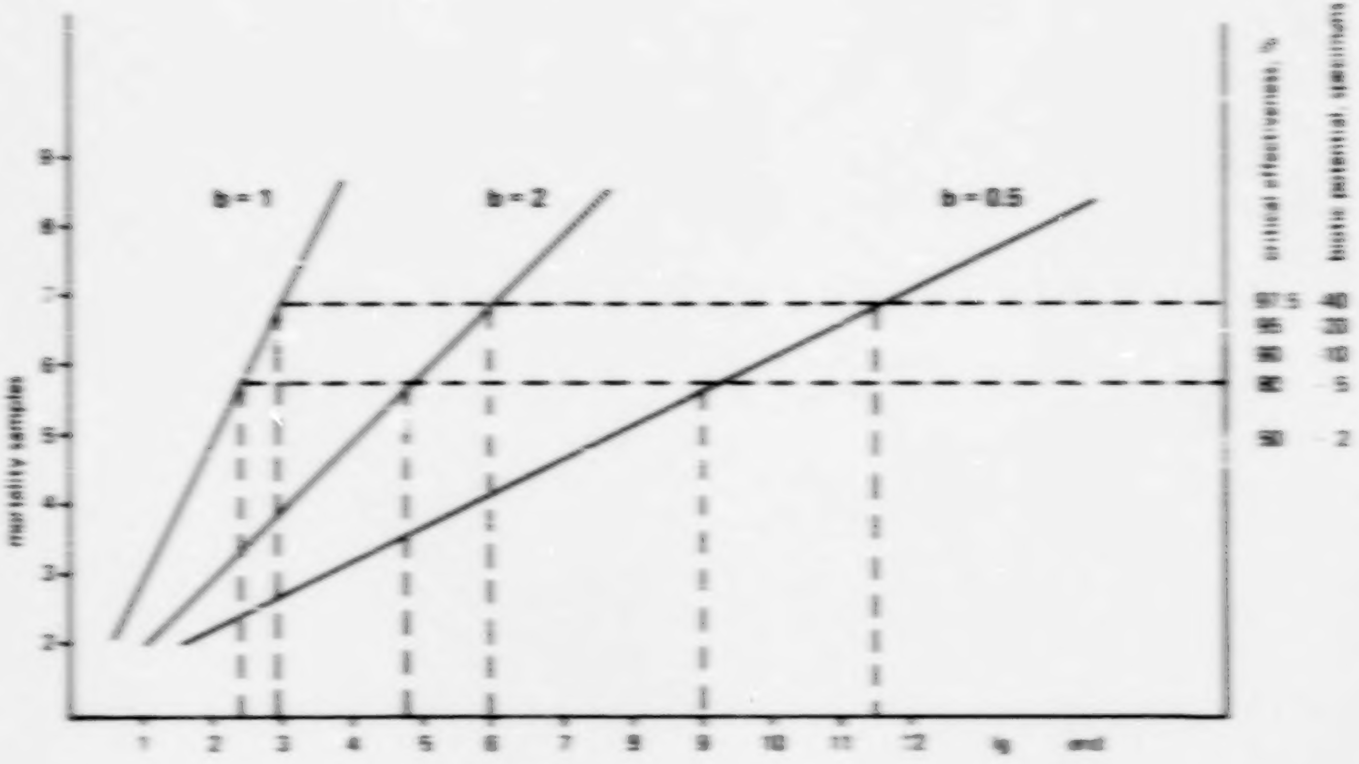

Figure 2. Schematic dependence between doses providing critical effectiveness for different levels of biotic potential and the type of effect produced by the probit (regression factors 2, 1 and 0.5).

poisons, as shown in Figure 2, can be regarded as typical for a number of cases.

On the basis of Figure 2 and by using the regression equation $Y = \bar{Y} + b\ (X - \bar{X})$, the conventional doses required to provide "critical effectiveness" for different values of biotic potential of the pest can be calculated. A plot then can be made which shows the potential changing in accordance with the varying pest resistance of the crop varieties which the pest attacks. As a sample calculation, a hypothetical pest was used in its original biotic potential (80 progeny from each female, sex ratio 1:1) resembles *Tetranychus urticae*. The results are shown in Table 1.

Thus, although in the case of an 8-fold decrease of the biotic potential (from 40 to 5) the "critical effectiveness" appears to decrease only slightly (from 97.5 percent to 80 percent, that is, only by a factor of 1.2), the doses required to achieve this drop sharply. Even in the least favorable of the cases examined the dose may be expected to decrease by a factor of 4, while for smaller values of the regression factor the effect of decreasing the dose exceeds by many times the effect of decreasing biotic potential. It should also be borne in mind that for polyvoltine varieties, such as *T. urticae*, the effect of decreasing the dosage multiplies since the critical effectiveness must be attained in each generation or at least with each spraying, and thus, the effect must be equal to the sum of effects on each generation or from each spraying. These calculations, of course, cannot form a basis for correcting the dosage or the number of sprayings used against the pest, and they are not intended for that purpose. They make it possible, however, to approach quantitatively the assessment of the probable effect of a pest-resistant variety in reducing the level of chemical treatments required for protection of the crop.

Under field conditions, the effect of the variety, as such, may be concealed behind a number of factors--for example, the presence of additional host plants, the effectiveness of chemical treatments, the existence of various kinds of shelters which enable the pest to avoid contact with the pesticide, temperature and humidity fluctuations and the presence of parasites and predators and how they are affected by the pesticides. These factors become aggravated if the pest is one which produces many generations during a season. It appears advisable, however, to attempt at least an approximate theoretical analysis of the effect of a resistant variety on reducing the scale of pesticide treatments.

The analysis produces irrefutable evidence that it is expedient and advisable to cultivate fully or even moderately resistant varieties which can reduce the reproduction potential of the pest. The extent to which the variety affects the decrease in abundance of the pest is shown by F. M. Uspenskiy's data in Table 2.

Table 1. Conventional insecticide dose required to reach critical effectiveness for varying values of the regression factor

Biotic potential (number of females in the progeny one female)	Critical effectiveness, percent	Dosage[1]		
		B = 2	B = 1	B = 0.5
40	97.5	1	1	1
20	95	0.69	0.31	0.23
10	90	0.45	0.21	0.05
5	80	0.27	0.08	0.006
Ratio of dose for biotic potential (BP) equaling 40 to dose for BP equaling 5		3.7	12.5	160

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[1] B = value of regression factor

Table 2. Change in fertility and survival rates of *Tetranychus urticae* K. feeding on different varieties of cotton

Cotton variety	Average number of eggs laid by one female	Number of larvae destroyed, percent
2036	98.6	5.5
8517	54.1	6.2
C-460 medium fibered	38.0	4.1
18819	37.2	4.1
35 - 1	8.5	25.0
02293 thin-fibered	5.4	25.0
6 - 46	3.2	40.0

Considering fertility, larval mortality and number of generations, Uspenskiy calculated that, on medium-fibered cotton in the Tashkent area for 11 generations, the reproduction potential of *Tetranychus* varies, depending upon the years, and ranges from 1.9 x 10^{16} to 8.1 x 10^{17} and in some years reaches 1 x 10^{24}. In areas located further south (thin-fibered cotton areas), even if the number of generations attains 15.5, the reproduction potential is 1.3 x 10^{10}, that is, it is smaller by a factor of millions and even billions. With such tremendous pest fertility, there is a need for the plants to be treated repeatedly with pesticides. An analysis shows, however, that treatment intensity will be considerably less, all other conditions being equal, for varieties having even a low level of resistance and on which the pest develops less rapidly.

In those cases when the pest produces a small number of generations during the growing season, the effect of resistant varieties on reducing the intensity of chemical control will manifest itself even more obviously under actual field conditions and is likely to approximate the computed values.

Although there have been a number of reports concerning the possibility of decreasing the pesticide dosage or the treatment frequency against pests on resistant varieties, there are virtually no direct data from which one may satisfactorily compare tests with calculations. Therefore, it would be desirable to conduct experiments requiring joint cooperation between plant protection specialists and toxicologists. The analysis of such studies should make it possible to develop sufficiently reliable methods of experimental and theoretical evaluation of the economic advisability of using specific resistant varieties in actual production. It also should be possible to develop criteria for an objective evaluation of an acceptable level of pest resistance of the varieties under cultivation.

One such criterion is a reduction in the fertility rate of the pest feeding on various selected individual host plants.

SUMMARY

Various investigators have shown that the physiological conditions of pests feeding on moderately resistant crop varieties may deteriorate resulting eventually in a reduction of their reproductive potential. Also, it is known that the lower the reproductive potential, the smaller is the portion of the pest population that must be destroyed to keep its density at a steady level or to bring it to a lower level. In this paper, an attempt is made to provide a quantitative estimate of the effect of a resistant variety in reducing the use of pesticides.

By using Chapman's equation and a series of dose-mortality ratios and various levels of reduction of the biotic potential of a hypothetical pest resembling *T. urticae*, it may be shown that by decreasing the biotic potential of the pest by a factor of 8 the nominal effective doses may be decreased by factors ranging from 4 to 160 (depending on the mode and speed of action of the toxicant) during treatment of one generation of the pest. The usefulness of conducting specialized experiments for the further development of this evaluation method is stressed.

Reduction of the reproductive rate of the pest as it feeds on different selected samples of the host plant may be used as one of the principal criteria for a quantitative evaluation of the long term effects of a pest-resistant variety on pest density and the need for chemical treatments.

HOST PLANT RESISTANCE TO COTTON INSECTS

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The purpose of this paper is to discuss those insect-resistant characters in cotton that are in an advance stage of development in breeding programs in the cotton belt of the United States. For additional information readers are referred to the review conducted by Maxwell, Jenkins and Parrott (17).

Resistant Qualities

Frego Bract

This recessive, monogenic character has been known for several years, having been found as a naturally occurring mutant in Arkansas. Jenkins and Parrott demonstrated its effectiveness in boll weevil suppression (7). They showed that frego bract will reduce boll weevil populations 66-94 percent below that on nonfrego bract cottons where a reproduction-diapause control program involving chemical insecticides is utilized to reduce the numbers of weevils entering hibernation (diapause) in the fall. Frego bract has also been shown to reduce boll rot (3) and to improve insecticide penetration and effectiveness (M. F. Schuster, Mississippi State University, personal communication). The primary problem associated with frego bract has been a greatly increased susceptibility to plant bugs, *Lygus lineolaris* and *Lygus hesperus* and to the cotton fleahopper, *Pseudatomoscelis seriatus*. This has greatly hindered the development of commercial varieties. L. S. Bird, Texas A&M University, has been able to incorporate the frego bract character into new backgrounds, which, when tested in Mississippi, did not exhibit ultra-sensitivity to plant bugs and, in fact, were more tolerant to these pests than the two most commonly grown commercial varieties (4).

Table 1 summarizes the full range of resistant factors found in cotton and reactions to the more important insect pests in the cotton belt.

Glabrous (Smoothleaf)

The number of hairs (pubescence) affects greatly the number of eggs

Table 1. Genetic sources of insect resistance found in cotton and currently being utilized in breeding programs in cotton (Texas, Mississippi, USDA and cooperating states of Louisiana and Missouri)[1]

Morphological or chemical characters identified	Boll weevil	Heliothis complex	Plant bugs, Lygus lineolaris and Lygus hesperus	Cotton fleahopper, Pseudatomoscelis seriatus	Spider mites, Tetranychus spp.	Whiteflies, Trialeurodes abutilonea
Frego (fg)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Nectariless (ne)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Smooth leaf (glabrous)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
High gossypol	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Pilose (pubescence)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Okra leaf	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Red color	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
"X" factor (G. hirsutum wild race)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Oviposition suppression factor (OSF) (G. hirsutum wild races)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Feeding suppression factor (G. hirsutum wild races and other species)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Early maturity (short season)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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[1] Research supported in part by Rockefeller Foundation Grant to Mississippi State University, Texas A&M University and the University of California, Davis.

[2] R, Resistant; N, no effect; S, susceptible.

deposited by *Heliothis zea* and *Heliothis virescens* on cotton. Lukefahr, Houghtaling and Graham have shown that smoothleaf reduces bollworm oviposition approximately 60 percent (11). In combination with nectariless, up to 80 percent suppression has been obtained. The more glabrous (super smooth) the plant, the higher the oviposition suppression. The primary problems associated with the glabrous conditions have been ultrasensitivity to the plantbugs, especially the cotton fleahopper and the detrimental affect of glabrous alleles on fiber quality (9,23). The source of the glabrous gene (G_3) present in most current breeding material is from the same original source (*Gossypium anomalum*). Recent studies with glabrous genes obtained from *Gossypium hirsutum* wild race stocks (North Carolina Smooth and LaMex) have not shown increased sensitivity to plantbugs and leafhoppers. It appears that these genetic sources of smoothness can be utilized for development of commercial smoothleaf varieties (M. Lukefahr, ARS, personal communication).

Nectariless

Lukefahr and Rhyne (15), Lukefahr, Martin and Meyer (14) and Lukefahr *et al.* (11) have reported on the value of the nectariless character in cotton for suppressing *Heliothis* sp. under caged conditions. Schuster and Maxwell reported the value of nectariless in suppressing plantbugs and fleahoppers but no significant reduction in *Heliothis* sp. (26). The common green lacewing was the only predator of significance reduced by the nectariless cottons. No real effect on the natural enemy complex was evident.

Nectariless cottons have been developed with good yielding ability and fiber quality (20). Several thousand acres of nectariless cottons are under seed increase by two of the major seed companies in the United States, and sufficient quantities of seed should be available to growers for the 1976 season.

The nectariless trait also reduces losses from boll rot (3).

High Gossypol

Cottons high in gossypol content have been shown to be effective in reducing larval growth and development and population buildup of *Heliothis* sp. (12). Cotton with both high gossypol and glabrous traits give a 2.6 percent reduction in population the first generation and permitted only a 1.8-fold increase between the first and second generation. This compared with a 12.5-fold increase on a commercial variety. The high gossypol character also has benn found to be an important source of resistance to cotton fleahoppers (M. Lukefahr, ARS, personal communication).

Intensive efforts are underway to transfer high gossypol into good agronomic cottons for the cotton belt, but progress has been slow until recently (25). There now are some good agronomic types that carry the high gossypol character. New sources of high gossypol content are being sought to supplement the single source (Socorro Island, *Gossypium hirsutum*) used so far. Workers are studying the inheritance of native and exotic alleles and gossypol content (8).

Glandless

There are two recessive genes, gl_2 and gl_3, which produce cotton plants devoid of gossypol glands in the pland and seed. There have been a number of glandless varieties developed in recent years because of the pressure for increased high quality sources of protein for human and animal consumption. Increased susceptibility of these glandless cottons were noted early in their development by a number of entomologists (5,13, 21,18,24). It is evident that gossypol has evolved in cotton as an important defense mechanism and, when removed, allows many insects not normally pests of cotton to accept it readily as a host plant.

Glandless cottons are being grown in special areas of the cotton belt, such as the High Plains of Texas, where there are few serious key pests, the most notable of which is *Heliothis* sp.

Okra and Super Okra Leaf

These modified restricted leaf types have no direct value in suppressing insects, except possibly whiteflies. However, the leaves provide for better penetration and coverage of insecticides. Some kill of boll weevil larvae in the dry and hot Southwest may be realized in the fallen squares because of high ground temperatures.

Red Color

This character, controlled by one dominant gene (R_1), has been known for many years and was first observed to be nonpreferred over green-leaf cotton by boll weevils as early as 1927 by Isley in Arkansas. The nonpreference exhibited by boll weevils is strictly in a choice situation, as boll weevils eat red cotton as readily as green if that is all that is available. Thus, there is little or no control value when solid-planted. However, researchers in Louisiana have shown that red cotton can be used when green cotton is stripped at intervals in the field. Approximately 80-90 percent of the field would be red with 10-20 percent green serving as a trap crop. The weevils concentrate in the green rows and only this portion of the field is sprayed, protecting predators and parasites in the major red portion of the field.

Although not adopted on a wide scale at present, this technique does hold promise as a component of a cotton pest management system in Louisiana and elsewhere. Commercial and near commercial lines of red cotton are available and may be obtained through Jack Jones, Agronomy Department, Louisiana State University.

Short-Season Cottons

Cottons that fruit prolifically and mature rapidly allowing early and once-over harvesting have many advantages. One primary advantage is the ability of these cottons to escape much of the late-season buildup of boll weevils, bollworms and other insect pests which often decimate the crop. Another major advantage is the ability to harvest the crop before adverse weather in the fall sets in, damaging quality and increasing loss. Short-season cottons have been primarily under development in Texas where several have been released through Texas A&M University (4,22). A number of experimental lines of semidwarf cotton are presently under test for bollworm and boll weevil escape and for adaptation to certain areas of Texas (1,2). Bird *et al.* (4) has reported on a number of adversity-multidisease-resistant okra and frego bract cottons that are early in maturity.

A short-season cotton (SP37) planted in a high-density pattern was recently grown in South Texas with greatly reduced amounts of nitrogen fertilizer (25 pounds per acre), was irrigated one time and had insecticides applied twice during early season. The short-season variety produced yields (800 pounds lint per acre) as great as those produced by standard commercial varieties grown in a conventional system and treated with 4 to 8 times more nitrogen (100-200 pounds per acre), twice the irrigation and 3 to 5 times more insecticide (6-10 treatments per season). In addition, the short-season cotton was harvested within 135 days of planting and approximately one month ahead of normal harvesting. This has great advantages if these cottons are grown on an area-wide basis, in that food and breeding sites of the pink bollworm and boll weevil in cotton fields may be removed by early harvest and stalk destruction before environmental conditions (for instance, short days and cool temperatures) are such as to force these pests into diapause. This type of system has potential for greatly conserving the use of the energy and fossil fuel-derived products required to produce cotton. It also produced profits of almost $100 per acre more than the conventional cotton production system.

An advance breeding line of a Delta-type cotton possessing approximately 20 days earlier maturity than present Stoneville and Delta pine types has been released through the Delta Branch Experiment Station, Mississippi State University. This line is now under seed increase and can be supplied to commercial seed companies and others through R. R. Bridge, Delta Branch Experiment Station. Nectarless cotton is currently being moved into this short-season Delta cotton.

Other Resistance Mechanisms

Some cottons found among the wild race collection of *Gossypium hirsutum* exhibited antibiosis to *Heliothis* sp. that could not be explained by gossypol concentration. This resistance was called Factor "X", and efforts are currently underway to identify the chemical(s) (10).

Tolerance to plantbugs has been detected in Stoneville cottons (19), and a plantbug suppression factor (mechanism not known) has been found in a number of lines in the wild race collection of *G. hirsutum*. Several of these sources are now under study for use in breeding programs.

A boll weevil oviposition suppression factor has been found in an number of photoperiodic lines from the wild race collection of *G. hirsutum*. Oviposition is suppressed 40 percent or more over that observed on commercial varieties. Several of the better sources have been crossed with upland commercial types, photoperiodicity-broken and further selection made. Breeding work is continuing at a rapid rate to move this resistance to more acceptable agronomic types (6).

Resistance to whitefly (*Trialeurodes abutilonea* (Haldeman)) was found in several obsolete varieties of *G. hirsutum* out of 277 evaluated in 1974. One line was selected for use in breeding for resistance to this insect. Crosses have been made and are currently being evaluated (Jenkins, personal communication).

Over 994 lines of cotton, including large numbers for the *G. hirsutum* race collection and from the *G. barbadense* collection, have been screened for resistance to the twospotted spider mite (*Tetranychus urticae* Koch.). No upland cotton was resistant. Some lines of *G. barbadense*, race stocks of *G. hirsutum* and hexaploid cottons from interspecific crosses showed some resistance (27). Genetic studies on the inheritance of the resistance is currently being conducted.

Combining Different Sources of Resistance to Cotton Pests

The long range objectives of the host plant resistance program in cotton in the United States is to combine several resistant mechanisms into adapted varieties providing protection against major insect pests. Good progress toward this goal is being achieved. For example, nectarless and glabrous have been combined for several years but not in the most desirable genotype. The D_2 gene for smoothleaf has not been a good source. New sources of smooth leaf have now been found and have been combined with nectarless. High gossypol has also been incorporated with glabrous and nectarless and shows good resistance to *Heliothis* sp.

and plantbugs. There are also combinations under test containing frego, nectariless and smoothleaf cottons. This combination provides levels of resistance to bollworms, plantbugs and boll weevil. A combination of red leaf, okra, nectariless and frego bract cottons has been developed to the near-commercial stage in Louisiana.

Okra leaf, frego bract, nectariless and earliness characteristics have all been combined along with other disease resistance mechanisms in an advance, early-maturing SP line in Texas. This advance line will soon replace TAMCOT SP37, an early, disease-resistant line currently very popular in several sections of Texas.

Cotton resistant to major pests is greatly needed today. With mounting problems associated with insecticide resistance, increased energy costs, scarcity and loss of effective pesticides, there is continual need to advance the field rapidly with proper support. Benefits from programs started 10 years ago with very little support are just beginning to be felt. Plant resistance to several major cotton pests is near reality as is evident from progress to date. Resistant varieties should and hopefully will form much of the foundation for cotton pest management programs of tomorrow.

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AN AREA-WIDE BOLL WEEVIL SUPPRESSION PROGRAM--ORGANIZATION, OPERATION AND ECONOMIC IMPACT

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Summary

Each year since 1964, a suppression program has been directed against the boll weevil, *Anthonomus grandis* Boheman, population along the juncture of the Texas High and Rolling Plains. The suppression effort has successfully prevented the westward spread of the pest into the more than 2 million acres of High Plains cotton. This program represents the largest coordinated effort ever undertaken to combat a cotton pest. It also serves as an excellent example of cooperation among state and federal agencies and producers.

Program evaluation indicates that the suppression effort has resulted in a significant economic return to the cotton industry and has reduced the total amount of pesticide required for cotton insect control in the area.

Introduction

The Texas High Plains, the largest cotton-producing area in the United States, has historically experienced few major cotton pest problems. For many years, the boll weevil, a key pest in most cotton growing areas of the state, was completely absent from the area. In fact, many entomologists considered that the high altitude, cold winters and scarcity of overwintering habitat of the High Plains presented an ecological barrier which the boll weevil could not penetrate.

However, by 1960, the boll weevil population had expanded its geographical range onto the fringes of the High Plains. By October 1963, weevil infestations extended into High Plains cotton approximately 20 miles west of the Caprock escarpment, a geological formation separating the High Plains from the adjoining Rolling Plains. Consequently, High Plains cotton producers were concerned that the boll weevil might become an established pest in the area and possibly spread into New Mexico.

At that time very little was known about the ecology of the pest in this fringe area of distribution. However, there were indications that the insect was capable of winter survival on the High Plains, and the potential for the continued westward spread of the population was recognized.

Program Organization

It was evident that a successful program to combat the spread of the pest would have to be a large-scale, well coordinated effort. In 1963, High Plains cotton producers represented by Plains Cotton Growers Incorporated, requested that state and federal agencies cooperate in the development of a program to halt the advance of the boll weevil into High Plains cotton.

The most promising method of preventing, or at least slowing, the advance of the weevil population appeared to be an insecticidal program designed to destroy potentially overwintering weevils before they entered overwintering habitat. This control technique, commonly termed "diapause control," was based on the premise of Brazzel, Davich and Harris (6), that an insecticidal program of 2-4 applications applied immediately before and during the harvest season would significantly reduce the overwintering boll weevil population. The diapause boll weevil control method had been tested and shown to be effective on relatively small cotton acreages (4, 5, 6). However, the implementation of this type of program on the massive basis required to significantly reduce weevil movement over a large area had not been attempted previously.

In 1964, a cooperative boll weevil suppression program was initiated by Plains Cotton Growers Incorporated, The Texas Agricultural Experiment Station, The Texas Agricultural Extension Service, U.S. Department of Agriculture, Texas Department of Agriculture and Texas Tech University. Costs of the program were shared equally by cotton producers and the U.S. Department of Agriculture. The actual application of the program was carried out by the Animal Plant Health Inspection Service, USDA.

The objective of the program was to stop the westward advance of the boll weevil by suppressing the population in a broad area along the margins of the High Plains.

Operation and Results

The first control effort was initiated on September 16, 1964, and consisted of four applications of ultralow volume malathion applied at the rate of 16 fluid ounces per acre to 295,000 acres of cotton along the juncture of the Texas High and Rolling Plains. Applications were made at 14-day intervals and continued until weevil food and oviposition sites were destroyed by a plant-killing freeze. The suppression effort in 1964 resulted in a reduction in the potential overwintering weevil population of 82 percent (Table 1). This was considered significant in view of the extremely heavy weevil infestations present at the onset of the program. Following the completion of the spraying operation, examinations of selected areas of boll weevil overwintering habitat confirmed a sizable reduction in the weevil population (Table 2).

In 1965, the suppression program was revised to fit the hypothesis of Knipling[1] that a program aimed at destroying the last reproductive generation of weevils would be more effective than one designed strictly to kill diapausing weevils before they left cotton. This approach was supported by research which indicated that in the High Plains area, the first potentially overwintering weevils of the season developed from eggs deposited from mid-August to early September (9). Therefore, in 1965 a two-phase suppression program was initiated on September 5 (1). Phase I consisted of three applications of ultralow volume malathion made at 5-day intervals to destroy reproductive females before they deposited eggs which might develop into diapausing adults. Phase II, basically the same program used in 1964, consisted of insecticidal applications at 10-14-day intervals until frost to destroy diapausing weevils remaining in the fields.

The suppression program has been continued each year since 1964 and is presently in its 12th year of operation. The programs conducted during the first 4 years of the suppression effort were very effective, resulting in reductions of the potentially overwintering weevil population as high as 99 percent (Table 1).

With the initiation of the fourth suppression program in September 1967, weevil infestations had been almost completely eliminated on the High Plains. During this period only 118,000 acres in the area were found to be infested. This represented a reduction of 177,000 acres in the size of the original control zone.

Since 1967, the program has been conducted on a more limited basis because of reduced finances. The mean number of insecticidal applications declined from 6.1 in 1965 to less than 3.0 in 1971-73. This has resulted in a corresponding decrease in the effectiveness of the suppression effort (Table 1). However, comparisons of overwintered boll weevil populations

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[1] Knipling, E. F. 1963. An appraisal of the relative merits of insecticidal control directed against reproducing versus diapausing boll weevils in efforts to develop eradication procedures. A letter dated January 28, 1963, addressed to members of the Cotton Insects Res. Branch, Entomol. Res. Div., Agr. Res. Ser., USDA.

Table 1. $\bar{X}$ no. of insecticide applications, acreage treated and estimated effectiveness of High Plains boll weevil suppression program, 1964-73

Year	$\bar{X}$ No. of applications	Acreage in control zone	Aggregate acreage treated	Estimated percent reduction of potentially overwintering weevil population[1]
1964	3.9	295,000	1,136,665	82
1965	6.1	250,000	1,512,540	99
1966	5.4	190,000	1,020,225	97
1967	4.2	118,000	501,024	86
1968	3.5	174,231	616,629	52
1969	3.5	217,000	768,000	43
1970	3.2	360,325	1,170,002	0
1971	2.8	133,361	377,544	69
1972	2.8	185,921	514,131	80
1973	2.9	222,515	652,279	0

[1] Estimates based upon sampling of adult weevil populations in suppression zone fields and untreated fields outside of the zone.

Table 2. Comparison of overwintering boll weevil populations in overwintering habitat in High Plains boll weevil suppression area and adjoining untreated areas

Date	Estimated number of overwintering weevils/acre habitat	
	Treated area	Untreated area
January 1964*	2,650	--
January 1965	281	--
January-February 1966	36	--
November 1966 - January 1967	45	11,293
February 1967	21	806
April 1968	8	484
January 1969	2,299	11,274
January 1970	1,636	2,033
January 1971	605	954
February 1972	89	4,033
January 1973	343	2,130
February 1974	65	387

*Samples taken before initiation of boll weevil suppression program.

in winter habitat in the suppression area and in adjoining untreated areas indicates that sizable reductions in the number of weevils entering overwintering habitat have been achieved with limited numbers of insecticidal applications.

Even with a reduction in effectiveness since 1967, the main objective of the program has apparently been met. At present, the distribution of the pest is less than that at the initiation of the program in 1964, and infestations generally remain below economic injury levels throughout the growing season. Although seasonal infestations within the Rolling Plains portion of the suppression zone are greater than during the low ebb of 1965-67, there is presently no evidence of the establishment of the population west of the suppression zone boundaries.

Concurrent research conducted during the suppression program has provided considerable information on the ecology of the pest in its westward limits of distribution. The weevil population in the High Plains area differs genetically from populations in Central and South Texas. The difference in genotype is indicated by the significantly greater percentage of High Plains weevils which enter diapause under inductive photoperiods (11). It is evident that the High Plains population is adapted to the area and not just a transient extension of the weevil population established to the east and south.

The weevil population suffers extremely high winter mortality in the High Plains area, with winter survival largely dependent upon the availability of suitable overwintering habitat (3, 9, 10). It is evident that the weevil population faces severe environmental resistance in the High Plains area. This explains how even marginally effective insecticidal suppression programs directed against the population have been able to limit the spread of the pest.

Late-season suppression of the potential overwintering population represents a considerable improvement in the insecticidal control of the boll weevil. Since the initiation of the program, the need for insecticidal treatments for weevil control during the growing season has been drastically reduced. This has resulted in an equally dramatic reduction in damage from the bollworm, *Heliothis zea* (Boddie), apparently due to the preservation of natural predators and parasites. Even though bollworm populations increase during the late-season treatments, the populations develop late and have not caused economic damage to the crop (2).

Research conducted on the effect of the program on non-target arthropods has shown that insecticides applied late in the season for weevil suppression have not resulted in a reduction of predaceous arthropods the following year (7). In addition, no adverse effects on wildlife, domestic animals or humans have been detected during the 12-year program.

Table 3. Amounts of insecticide applied and cost of High Plains boll weevil suppression program, 1964-73

Year	Gallons insecticide applied[1]	Total cost[2]
1964	123,618	$1,728,777.00
1965	189,068	1,746,779.00
1966	116,437	1,024,461.20
1967	56,273	590,839.26
1968	71,901	689,366.75
1969	86,922	788,372.92
1970	138,869	1,234,855.44
1971	45,329	518,568.03
1972	59,891	650,400.50
1973	77,010	826,255.84
Total	964,918	$9,808,676.30

[1] ULV malathion was the major insecticide used in the suppression effort. 33,075 gals of azinphosmethyl were applied on a test basis during the period 1967-70.

[2] Includes insecticide, application and survey costs.

Data now available indicate that the greatest natural barrier to weevil establishment on the High Plains is the scarcity of suitable overwintering habitat and high winter mortality. However, there are areas of favorable overwintering habitat in the area, especially in the southern and western portions of the High Plains. There is little doubt that had the suppression program not been initiated weevils would be established in many aras of the High Plains and possibly in New Mexico.

The economic benefits from the program are difficult to derive, but even the most conservative estimates indicate significant economic gains from the program. During the first 10 years, a total of 964,918 gallons or about 9,105,027 pounds of insecticide were applied at a cost of $9,808,676.30 (Table 3). A recent economic study indicates that, without the program, production costs in the affected area would have been increased by at least 8 percent or about $12.7 million annually (8). Without the cooperative late-season suppression effort, producers would be required to increase the amount of insecticide applied to cotton by approximately 8.2 million pounds annually.

Therefore, in the absence of the program, increased production costs might exceed the 10-year cost of the program in 1 year. In addition, the amount of insecticide required to combat the weevil during a single season of heavy infestations using conventional in-season control methods would almost equal the total amount of insecticide applied during the first 10 years of the program.

All available information indicates that the boll weevil suppression effort, from both the economic and environmental standpoint, has been a worthwhile venture.

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THE IMPLEMENTATION OF AN INTEGRATED INSECT CONTROL PROGRAM

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One of the most challenging jobs in United States cotton production is designing an insect management program that will be accepted by farmers and incorporated into their production systems. The fruits of research are lost if programs are not developed to effectively incorporate new technical developments into agricultural production. Grower acceptance of the principles of insect management is a primary objective. Because today's cotton farmer is an independent, free-thinking businessman, the advantages of a well-designed insect management program must be clearly demonstrated by way of a broad-based educational program.

Entomologists saw a need to increase the rate of adoption of integrated insect management. Farmers were not accepting even the most basic principles, such as most advantageous planting periods, use of economic thresholds, thorough destruction of postharvest crop residues and so on. After much time spent analyzing this enigma, the conclusion was reached that the problem was being greatly oversimplified. A great deal of educational work was required to overcome traditional practices, because growers basically viewed cotton insect control as a mystery. Farmers expressed their need for an entomological specialist to assist them in making difficult, key insect control decisions and to aid them in designing an insect management program suited to their particular geographic regions.

Starting in 1977, by virtue of an APHIS-USDA grant, the 14 major cotton-producing states received funding for the implementation of a pest management program. Based upon variances in insect pest problems, production techniques and geographic location in Texas, four areas were selected as pilot sites to begin the program: the Lower Rio Grande Valley, South Texas, the Texas Blacklands and the Trans-Pecos.

Organization

The organizational design of the Texas program is unique. County Extension entomologists, under the direction of a project leader, are located at each site. County entomologists are college graduates with field experience. The county entomologist resides in the area year-round and has responsibilities for hiring and training sub-professionals (scouts) to inspect farmers' cotton on a weekly or bi-weekly basis for appearance of pest species and damage, the incidence of beneficial insects, the fruiting rate of the cotton, field moisture conditions and so on. The scout delivers a Producer's Cotton Insect Report to the farmer. The county entomologist also receives a copy of the report. The report provides the aforementioned information plus the economic threshold levels for each key pest. The farmer can compare counts of pest numbers and damage with the economic threshold to determine the possible need for an insecticide application. The county entomologist is available to assist the farmer with his decision.

Scouting or field inspection is only one phase of the program. By using examples gained from past program experience, the overall production of the cotton as it relates to insect management can be demonstrated.

Application

South Texas and the Lower Rio Grande Valley

Since Texas has 9 degrees of northern latitude, the Lower Rio Grande Valley is located at 26° N. in a subtropical climate. The pest management program stresses early planting (February 15–March 1) of an early-maturing, rapidly fruiting, semideterminate cotton variety. Such a variety and the method in which it is grown — that is, with proper irrigation and fertilization — is the single most important factor in managing the key cotton pests of the Lower Rio Grande Valley. The key cotton pests in order of seasonal occurrence are (1) the cotton fleahopper, *Pseudatomoscelis seriatus* (Reuter); (2) the cotton boll weevil, *Anthonomus grandis* Boheman; and (3) the cotton bollworm, *Heliothis zea* (Boddie) /tobacco budworm, *Heliothis virescens* (Fabricius) complex. The rapidly fruiting cottons condense or shorten the period of susceptibility to insect attack. The cotton fleahopper, an early-season pest, attacks the primordial buds and can be managed by careful field inspection and precise timing of insecticide applications when economic thresholds are passed. Every effort is made to keep early-season insecticide applications to a minimum in order to preserve populations of parasites and predators which help suppress cotton bollworm populations. Boll weevil management involves a season-long strategy. This may require some early-season insecticidal control to allow a 2- to 3-week period for rapid fruit set. With favorable growing conditions, these rapidly fruiting cottons will have the majority of their cotton produced on the plant before damaging, second generation boll weevil populations develop. The cotton is grown so as to escape damaging late-season insect populations. This escape character is also extremely important in dealing with the insecticide-resistant tobacco budworm. Usually by July 10, the majority of the *Heliothis* population complex is the resistant *H. virescens*. If the cotton is grown properly, most of the bolls will be old enough to escape damage by the tobacco budworm. The incentive for early harvest is further encouraged by the desire to escape weather problems encountered by the hurricane season, or rainy season, that begins in August. Finally, thorough destruction of crop residues after harvest is recommended to reduce the food supply of boll weevils going into diapause and to prolong the host free period.

Trans-Pecos

Although the Trans-Pecos area is relatively free of boll weevils, a similar short-season production approach is recommended to escape late-season populations of resistant cotton bollworms and tobacco budworms. Also, like most of the Lower Rio Grande Valley, cotton is produced under irrigation. Strong emphasis is placed on proper water and fertilization management to reduce lush, vegetative growth that attracts the cotton bollworm and the tobacco budworm. These two key pests are the focal point of the scouting, or field inspection, phase of the insect management program. Premature applications of insecticide often result in destruction of beneficial insects. Proper timing of insecticides based on field inspection is stressed. Therefore, as in the Lower Rio Grande Valley, a program of total crop management is recommended.

Blacklands

As in the other two areas, a short-season approach is recommended in the Central Texas Blacklands. Cotton is produced under dryland conditions in the Blacklands. Early planting, rapid maturation and careful timing of insecticide applications based upon field inspection are again stressed. The cotton fleahopper and the cotton boll weevil are managed with an early-season program. Beneficial insects are extremely efficient at suppressing cotton bollworm and tobacco budworm populations in mid- to late-season. As the grain sorghum matures, beneficial insects move from grain sorghum into cotton. Therefore, a grain sorghum insect management program is included in the cotton program to reduce the likelihood of the destruction of beneficial insects in grain sorghum by unneeded insecticide applications. This is an example of how a multiple-crop insect management program can be used to achieve total management.

These examples explain the general strategy employed in the Texas program. Year-round educational programs are conducted by the county entomologist. News releases during the production season alert other area farmers to insect problems. Close work with cotton and grain sorghum producer associations offers further means for program exposure.

Discussion

An economic evaluation of the 1973 and 1974 programs showed a total net profit increase of $2,059,000 for the program's farmers when compared to a similar group of non-participating farmers. The program included 36,000 acres each year. This increase was due to a decrease in insecticide expenditures, an increase in returns from yield or both. An environmental evaluation revealed an estimated 82,000-pound reduction in pesticides applied to the 36,000 program acres compared with non-program farmers. Yields were increased by 4,200 bales.

The success of initial pilot programs has resulted in statewide expansion of this concept. With the help of Texas cotton producer associations, state-appropriated funds have been secured to begin seven more programs. Additional federally funded programs will be added later this year.

Successful implementation of insect management programs depends upon making growers aware of (1) economic threshold levels, (2) the value of reliable field scouting, (3) the need to reduce the indiscriminate use of pesticides, (4) the value of beneficial insects, (5) the availability of a professional entomologist, (6) the need for total crop management as a basis for insect management and (7) the need to show growers the economic and environmental advantages of sound insect management programs. These factors have lead and will further lead to a major shift in grower attitude toward the adoption of the basic principles of insect pest management by way of education.

THE INTEGRATED CONTROL OF ARTHROPOD PEST DISEASES OF COTTON IN THE U.S.S.R.

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In the U.S.S.R., cotton is one of the basic industrial crops. It is grown mainly in the republics of Central Asia and Transcaucasia. The principal republic where the long fiber variety is grown is Uzbekistan, while the short fiber variety is grown in Turkmenia and in part of Tadjikstan and Uzbekistan. In recent years scientists in the U.S.S.R. have thoroughly inspected cotton fields and have found that cotton is attacked by more than 200 species of pests, mainly insects. However, there also are dozens of species of other pathogenic organisms, pathogenic fungi, bacterial and virus diseases. The majority of the cotton pests have transferred to cotton from wild growing plants. They have then adapted themselves to the cotton plant.

The Soviet Union is free from many harmful pests that are a scourge in other countries. The U.S.S.R. does not have the boll weevil (*Anthonomus grandis*), the pink bollworm (*Pectinophora gossypiella*), the *Pantomorus leucoloma* or the cotton anthracnose or Texas root rot disease.

The cotton pests are diverse in kinds, and weeds serve as the primary source of pest infestation on cotton. Hence, control of weeds helps to assure a better harvest of cotton.

Agrotechnical cotton cultivation in the republics where the crop is grown is of exceptional importance. All of the cotton in the Soviet Union is grown under irrigation, and therefore, an effective irrigation system is considered as the principal aid for obtaining a high crop yield.

It should be noted that, of the 200 species of pests and dozens of diseases to which cotton is susceptible, not all of them are hazardous. The pests that produce the most damage are spider mites, the cotton bollworm, three different species of aphids, the cutworm, the beet webworm (*Loxostege sticticalis*), the onion (or tobacco) thrips (*Thrips tabaci*), three species of click beetles, the beet armyworm (*Laphygma exigua*), the cutworm moth (*Chortophila florilega*) and the alfalfa plant bug (*Adelphocoris lineolatus*). In the foothill regions where cotton is cultivated, the Asiatic locust, the *Locusta migratorius* (Acrididae), field crickets and cicadas are found. Among the diseases, the most dangerous are Verticillium wilt, and, to a lesser degree, fusarium wilt. Economic damage to cotton, particularly during the first phase of its growth, is caused by the root diseases. None of the other pathogens constitute a serious threat to cotton.

In the U.S.S.R., cotton is damaged during each stage of development. The seeds can be injured by caterpillars, darkling beetles, cutworms, and root rot or root mold.

The root system is exposed to injury mainly by the cutworm, and the leaves are injured mainly by spider mites, aphids, the cutworm moth, the beet webworm and other pests. The fruiting structures may be damaged by the cotton bollworm, the alfalfa bug and the cotton aphid.

Spider mites are the most harmful pests of cotton. They are found in all of the zones where cotton is cultivated and inhabit more than 150 species of plants. In the principal cotton-growing regions, spider mites continuously develop and produce 15 generations which overlap. They seem to have a propensity for consuming leaves, but the mites damage more than just the leaves, which have a poorly developed spongy parenchyma on their lower sides. With their stylets the mites perforate this weakly developed spongy parenchyma and freely feed on the spiny fiber of the leaf where the granules of chlorophyll are chiefly found. The crumbly spongy fiber of the leaf enables the pest to penetrate into the fiber and feed on the succulent tissue, and, as a result of this abundant food, the fertility of the female mites is increased.

Studies of the spider mite have made it possible to associate its feeding habits with resistance of cotton and other plants to this pest. In order to avert the damage which this pest has caused in the Soviet Union, a system of prophylactic and extermination measures, using agrotechnical, organizational-economic, chemical and other procedures has been developed in practice.

The cotton bollworm in some years causes considerable damage to cotton. Potential damage can reach up to 20 percent of the yield. The first generation of the cotton bollworm develops on various weeds, lucerne, tomatoes and bengal grain. Cotton is threatened after the plant enters the budding stage, when the now-developed second generation of the worm is most harmful. The third and fourth generations are dangerous when cotton is planted late or when, as a result of unfavorable weather, the crop must be replanted. The duration and degree of damage to plants depends on ecological conditions and the biochemical content of the plant. The development of the caterpillar depends on whether, during the first growth stages of the plant, they feed on the fruiting forms of the cotton. As a result it is of great significance in the control of the cotton bollworm that proper prognosis and a well-formulated phenological assessment of the problem are applied. Great attention is being given in the U.S.S.R. to predicting outbreaks of the cotton bollworm, as well as of many other pests. A forecast has, in many cases, decided the fate of the harvest and made for lower environmental pollution by making it unnecessary to use chemical pesticides.

Not every year, but quite often, young cotton plants are exposed to severe damage by the cutworm moth. Outbreaks of this pest depend upon ecological conditions in the spring season. When there is little rainfall during spring, the development of the cutworm moth is retarded. The same thing also happens with the winter bollworm on cotton. Under very arid conditions the wind blows away the upper soil layer which adversely affects the winter bollworm.

Among other sucking pests, cotton is also damaged by the melon (or cotton) aphid (*Aphis gossypii*), the acacia aphid (*Aphid laburni*), the greater cotton aphid (*Acyrthosiphon gossypii*) and tobacco thrips.

Among diseases of cotton, root rot or mold poses a threat to cotton seedlings during a rainy and cold spring. Verticillium wilt becomes widespread, and the necessity of controlling this disease continues from year to year. Although it is true that the Tashkent I, II and III varieties of cotton, introduced by Uzbek cotton breeders, show a resistance to the pathogens of this disease, the use of these varieties alone does not eliminate all damage from wilt. The discovery of a better means of wilt control still remains a major problem to cotton production in the Soviet Union.

Every cotton-growing republic has a zonal system of cotton pest and disease control. However, the rules governing their establishment are extremely complex. In a system of planned agriculture, the organizational-economic measures which are directed toward improving the general cultivation of a cotton-growing economy are of great significance. These measures are directed toward continuous development of new lands which harbor many kinds of pests.

The expansion of the planted area, field planning, territorial land development, the opening up of new lands and the introduction of crop rotation are all utilized in agriculture. The great significance of a system of measures lies in the agrotechnical means to bring about (1) normal plant growth and development, (2) fertilizer use, (3) water supply, (4) soil tillage and (5) the cultivation of healthy plants which, to a great measure, are resistant to pests and diseases. Prophylactic chemical treatments are carried out for the destruction of weeds. An essential method is the pretreating of seeds with toxic chemicals before sowing, which prevents seedling diseases and damage to the root system. During the vegetative period, a number of chemical treatments may be used against a variety of weeds and rodent pests. In controlling spider mites and weeds, treatment with systemic poisons (Anthio, dimethoate) is alternated with a treatment with a sulphuric compound or other specific preparations. Such a pattern of alternating insecticide treatments prevents the formation of large aphid populations which are resistant to toxic chemicals. In combating the winter bollworm, chemical preparations of 2 percent gamma-isomer GKhTsG, 12 percent dust GKhTsG, 25 percent powdered GKhTsG in fosmuk (sic) are not only used but also the egg parasite, ovicide *Trichogramma* are utilized. Polidofosh, phosfolan, carbaryl, GKhTsG dust and a bacterial preparation of dendrobacilline in a mixture with small doses of pesticides are used against the cotton bollworm and the cutworm moth.

Crop rotation with alfalfa and cotton are of great importance in the control of wilt. Besides alfalfa, corn and jugar (sic) can also be used. Among the chemical preparations used to control wilting is carbamide (6 kg per hectare) in a 1.5 percent solution.

Proper harvesting and disposal of field residues of cotton also is an important factor in controlling pests and diseases. In controlling weed growth, herbicides have been successfully used. Perennial weeds can be killed with dalapon (40 kg per hectare) applied before the land is plowed in the autumn or shortly thereafter. In controlling annual weeds, just before harrowing in preparation for sowing, the herbicide Treflan can be spread at 5-6 kg per hectare in 400-600 liters of water per hectare. During sowing Cotoran or prometryn can be applied, using the strip method. The standards for spreading these varies from 1 to 2.5 kg per hectare. A proper and well-timed utilization of this system of measures to control pests, diseases and weeds with regard to cotton produces excellent results, from an economic standpoint. In many collective farms in Uzbekistan and Tadjikstan and in the other republics of Central Asia, the yields of cotton have been increased in recent years by 15-20 percent. Economic profit still is, in many ways, dependent upon the proper introduction of prophylactic preventive measures which control the harmful organisms which may affect cotton yields.

MANAGEMENT OF THE WEED PESTS OF COTTON (*Gossypium hirsutum* L.)

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Introduction

Management of weed pests is a critical factor in the production of cotton and represents a significant expenditure of the production costs. "Weed management," in contrast to "weed control," implies the utilization of all forms of weed science technology available which will assure a minimum effect of weeds on the crop. The weed management concept can be integrated into an overall pest management program.

A management approach to problem solving requires correct recognition of the problem and a clear idea of the methods by which the problem can be solved. In weed management, the first step is recognition of significant weed pests. A survey conducted in 1973 revealed that while many weed species occurred within the U.S. cotton belt, relatively few species could be considered major weed problems (9). They include, however, both monocotyledonous and dicotyledonous annual and perennial species. The more troublesome weeds in cotton include species within the genera *Cyperus*, *Ipomoea*, *Sorghum*, *Xanthium*, *Amaranthus*, *Digitaria*, *Euphorbia*, *Panicum*, *Brachiaria* and *Sida* (9,45). Species within the genera *Solanum* and *Anoda* are rapidly becoming serious weeds in cotton.

Although one would expect different weeds to be troublesome in different geographical regions of the world, it is interesting to note that two of these species are among the most troublesome weeds all over the world (42).

Weed populations in cotton are not static but are extremely dynamic. Frans, as early as 1969, reported changes in weed species in cotton fields of the southern United States (31). He suggested that widespread use of trifluralin was a factor in the general reduction of many annual grass weeds and an associated increase in the prevalence of resistant broadleaf species. Another factor in population shifts is the decrease in the use of hand labor which formerly was effective in controlling spot infestations of certain weeds. Unavailability of cheap labor forced an excessive dependence on chemicals for weed control. Consequently, mechanical weed control techniques have only recently begun to be integrated with chemical control in weed management.

Numerous studies involving herbicides, cropping sequences and selected cultural practices illustrate the magnitude of weed population shifts (23,24,69). Research involving various herbicides in rotations of corn (*Zea mays* L.) and soybeans (*Glycine max* L.) shows the effectiveness of repeated use of a thiocarbamate-type herbicide in reducing prevalence of *Cyperus esculentus* L. (15). *Xanthium pensylvanicum* Wallr. populations generally were higher in soybeans than in corn, regardless of the method of weed control or herbicides used. High populations of *Cassia obtusifolia* L. developed in soybeans treated with trifluralin.

Weed-Free Requirement and Tolerance of Cotton to Weed Competition

In this research cotton has been found to require approximately 8 weeks of weed-free maintenance for production of maximum yields when competing with a mixed population of annual grass and broadleaf weeds (11). A similar weed-free requirement was reported for "spring" cotton in Mexico; however, "winter" cotton required approximately 17 weeks of weed-free maintenance for production of maximum yields (60,61). Nitrogen fertilization at rates up to 100 kilograms per hectare (kg/ha) does not affect the competitive relationship between cotton and a mixed weed population (17). The weed-free requirement may be considerably shortened, however, with 53-cm row spacing, compared with 79- and 106-cm row spacing (62).

Cotton will recover completely from substantial competition early in the growing season if the weeds are removed before the critical period. Under Alabama conditions, competition by a mixed population of weeds for less than 6 weeks after cotton emergence did not reduce yields. Row spacing apparently does not influence the critical period of weed competition.

Arle and Hamilton (4) showed that under irrigated conditions weeds allowed to compete with cotton after the first or second irrigation caused significant yield reductions. Competition beginning after the third or fourth irrigation did not result in yield reduction.

Economic Thresholds of Weeds in Cotton

Although many weed management practices are used *a priori*, the development of effective postemergence weed management techniques enables the grower to control weeds after their establishment. Postemergence applications of herbicides are an added cost factor, however, and should be used only when necessary. The question arises "When is necessary?" Little research has been conducted into the economic thresholds of specific weed species in cotton.

As few as a single *Cassia obtusifolia* L., *Ipomoea* sp., *Amaranthus retroflexus* L. or *Xanthium pensylvanicum* Wallr. plant per meter of row resulted in significant yield reductions of cotton (12,13). While competition from many weed species is similar on either sandy or clayey soils, *Amaranthus retroflexus* L. was found to be more competitive with cotton on clayey soil. In Texas, weed scientists reported seed cotton yields of 363, 321, 220 and 130 kg/ha when grown with *Amaranthus* sp. at a density of 1 weed per 2.8, 1.4, .7 or .3 meters of row (65). Yield of the weed-free control was 667 kg/ha.

Dense stands of *Cyperus esculentus* L. (up to 100 plants/m of row) competing with cotton all season reduced yields 34 percent compared with weed-free cotton and delayed maturity of cotton (52). Shorter periods of competition resulted in less reduction in yield. Fiber properties of cotton were generally not affected by *Cyperus* competition. Garner and his co-workers showed that grass weeds that emerge 2 or 3 months after planting of cotton may cause no reduction in yield or quality (33).

The competitiveness of weed species differs markedly with location and growing conditions. Ivy and Baker (47) reported severe competition from *Sida spinosa* L. in Mississippi. *S. spinosa* populations of 130 plants/m^2 that competed with cotton all season reduced yield 41 and 37 percent in consecutive years. In Alabama, however, *S. spinosa* has been far less competitive (18). Research is continuing to determine the economic threshold of certain weed species in cotton.

Methods of Managing Weeds in Cotton

Cultural Practices

Judicious use of cultural practices is of primary importance in successful weed management. Indeed, many of these practices are free or are of minimal cost. Full employment of the cultural concept of managing weeds in cotton involves starting the crop in weed-free soil. A well-prepared seedbed without established weeds allows the cotton seedling to compete favorably with germinating weed seedlings and also facilitates later weed control operations.

Cropping practices which favor growth of the cotton plant over weed flora contribute substantially to control of weeds through the competition exerted by the crop. As shown previously, cotton may become sufficiently competitive by 8 weeks after emergence, so that further weed control is unnecessary. Row spacing, stand and perhaps other factors may influence the particular time period at which competitive dominance is established.

Certain weed species are often more effectively attacked in crops other than cotton. *Xanthium pensylvanicum* Wallr., which is relatively difficult to control in cotton, is easy to control with the phenoxy and other herbicides in corn and sorghum. Crop rotations, particularly when coupled with herbicide rotations, can be effective in reducing populations of certain weeds. Fallow in conjunction with repeated disking or plowing is effective in reducing the population of viable *Sorghum halepense* (39,57,58).

Mechanical cultivation has been used extensively to control weeds in cotton (27). Numerous devices have been developed over the years which do an effective job of uprooting, covering and cutting weeds below the soil surface. Traditionally, cultivation has been considered beneficial from the standpoint of both weed control and improved soil conditions. However, recent research on Decatur clay loam and Hartsells fine sandy loam in Alabama indicates that control of weeds is the only benefit that may be attributed to mechanical cultivation of cotton (14).

Before the availability of herbicides, the primary means of controlling weeds in the drill row was by hand hoeing or pulling. Where weeds are abundant, up to 20 hours per hectare of manual labor were required to remove weeds (36). Covering seedling weeds with soil moved into the drill row by tractor cultivators has been effective in some situations. Unshielded cultivation was superior or equal to shielded cultivation as a weed control measure (43). On the other hand, replacing one or more postemergence herbicide applications with unshielded cultivation resulted in reduced control of weeds. Cultivation with sweeps alone was not effective in controlling a mixed population of grass and broadleaf weeds (25).

Flame Treatments

Small weeds can be effectively controlled by flame (44,54,66). Cotton is particularly adapted to flame cultivation because of its relatively tough bark, even on young cotton seedlings or plants. An advantage of flame cultivation is the lack of residue in either the soil or cotton plant. However, the expense and limited supply of natural gas have slowed development of this method of controlling weeds in cotton.

Biological Methods

Little research has been directed toward development of biological methods of weed control for cotton. Several reports indicate that geese effectively control certain weeds in cotton depending upon selectivity by the birds (35,48,55). Two or three geese per hectare generally control species within the genera *Cynodon*, *Sorghum*, *Cyperus* and *Digitaria*. However, species of *Amaranthus*, *Xanthium* and *Chenopodium* are not controlled. In addition, difficulty in managing geese has prevented this from becoming a widely used method of weed management in cotton.

The success of Daniel et al. (20) in controlling *Aeschynomene virginica* (L.) B.S.P. with the fungus *Colletotrichum gloeosporioides* (Penz) Sacc. f. sp. *aeschynomene* in *Oryza sativa* L. offers hope in biological control of weeds in cotton.

Chemical Control

Because of a high degree of efficiency and effectiveness, ease of manipulation and adaptability to varied situations, chemical control of weeds has become routine in cotton production. Although herbicides were quickly accepted for use in cotton in the 1950's, the proliferation of materials and extensive application occurred in the 1960's. Presently, over 95 percent of the U.S. cotton crop is treated with herbicides.[1/] In many areas of the United States, cotton receives more than one application in a given season (59). There are herbicides currently labeled for use during all stages of cotton growth from before planting to cotton maturity.

Preplant Foliar Treatments

These are treatments made to foliage of emerged weeds after land preparation but before cotton planting. Paraquat is effective in controlling emerged vegetation in the stale seedbed concept of seedling establishment. It will effectively kill small annual weeds, but lack of significant translocation of the herbicide to root systems often prevents acceptable control of large annual or perennial weeds. Paraquat also has been evaluated as a directed postemergence treatment for weed control in cotton (64).

Dalapon is used primarily for control of *Sorghum halepense* (L.) Pers. before planting cotton. Because of the slowness of new *S. halepense* growth in the spring, application of dalapon before the early cotton plantings results in less-than-maximum effectiveness of the herbicide in controlling *S. halepense*.

[1/] Common and chemical names of herbicides presently labeled for use in cotton in the United States are shown in Table 1.

Table 1. Herbicides presently labeled for use in cotton in the United States.

Common Name	Chemical Name	Primary Method of Use
dalapon	2,2-dichloropropionic acid	Preplant foliar
glyphosate	*N*-(phosphonomethyl)glycine	Preplant foliar
paraquat	1,1'-dimethyl-4,4'-bipyridinium ion	Preplant foliar
butralin	4-(1,1-dimethylethyl)-N-(1-methylethyl)-N-(phenylmethyl)propanamide	Preplant incorporated
dinitramine	N^4,N^4-diethyl-α,α,α-trifluoro-3,5-dinitrotoluene-2,4-diamine	Preplant incorporated
fluchloralin	N-(2-chloroethyl)-2,6-dinitro-N-propyl-4-(trifluoromethyl) aniline	Preplant incorporated
trifluralin	α,α,α-trifluoro-2,6-dinitro-*N*,*N*-dipropyl-*p*-toluidine	Preplant incorporated
penoxalin	N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine	Preplant incorporated
profluralin	N-(cyclopropylmethyl)-α,α,α-trifluoro-2,6-dinitro-*N*-propyl-*p*-toluidine	Preplant incorporated
nitralin	4-(methylsulfonyl)-2,6-dinitro-*N*,*N*-dipropylaniline	Preplant incorporated
EPTC	*S*-ethyl dipropylthiocarbamate	Preplant (Preemergence) injected
fluometuron	1,1-dimethyl-3-(α,α,α-trifluoro-*m*-tolyl)urea	Preemergence and Post-emergence
diuron	3-(3,4-dichlorophenyl)-1,1-dimethylurea	Preemergence and Post-emergence
methazole	2-(3,4-dichlorophenyl)-4-methyl-1,2,4-oxadiazolidine-3,5-dione	Preemergence and Post-emergence
prometryn	2,4-bis(isopropylamino)-6-(methylthio)-*s*-triazine	Preemergence and Post-emergence
DCPA	dimethyl tetrachloroterephthalate	Preemergence
diphenamid	*N*,*N*-dimethyl-2,2-diphenylacetamide	Preemergence
dipropetryn	2-ethylthio-4,6-bis(isopropylamino)-*s*-triazine	Preemergence
alachlor	2-chloro-2',6'-diethyl-*N*-(methoxymethyl)acetanilide	Preemergence
Bensulide	*O*,*O*-diisopropyl phosphorodithioate *S*-ester with *N*-(2-mercaptoethyl) benzenesulfonamide	Preemergence
monuron	3-(*p*-chlorophenyl)-1,1-dimethylurea	Preemergence
linuron	3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea	Lay-by
norflurazon	4-chloro-5-(methylamino)-2-(α,α,α-trifluoro-*m*-tolyl)-3(2H)-pyridazinone	Preemergence
norea	3-(hexahydro-4,7-methanoindan-5-yl)-1,1-dimethylurea	Preemergence
perfluidone	1,1,1-trifluoro-N-[2-methyl-4-(phenylsulfonyl)phenyl] methanesulfonamide	Preemergence
propachlor	2-chloro-*N*-isopropylacetanilide	Preemergence
tetrafluron	3-tetrafluoroethoxyphenyl-N,N-dimethylurea	Preemergence
MSMA	monosodium methanearsonate	Postemergence
DSMA	disodium methanearsonate	Postemergence
TCA (Glytac)	ethylene glycol bis (trichloroacetate)	Postemergence (Spot)

MSMA is effective against both *Cyperus* and *Sorghum* species. This is a particularly effective treatment for control of the sedges because both *Cyperus esculentus* L. and *C. rotundus* L. often emerge early, and one or two herbicide applications are possible before cotton emergence.

Preplant Incorporated Treatments

These herbicide applications are made up to 2 months prior to planting cotton and are mixed into the upper soil zone by tillage equipment such as disks or rotary hoes. This particular application technique became extensively used with the development of trifluralin (26). Numerous methods of incorporation have been described (32). Few herbicides have exerted the impact on a crop that trifluralin has exerted on cotton. Its effectiveness in diverse soil conditions, its degree of selectivity and modest cost assured quick acceptance of this herbicide by cotton growers. Because of trifluralin's high degree of activity and persistence, the population of many annual grass weeds has been significantly lowered in cotton fields.

A number of investigators have reported that trifluralin inhibits root development of cotton (1,37,41,53,67). Hassawy and Hamilton (40) and Arle (2) have shown that in the presence of phorate, trifluralin-treated plants produced more lateral roots than plants treated with trifluralin alone. Other organophosphorus chemicals used with trifluralin were ineffective or less effective than phorate in mitigating the effects of trifluralin on cotton. IAA and kinetin applied together with trifluralin have also been reported to mitigate the effects of trifluralin on lateral root development of cotton (41).

Nitralin, dinitramine and profluralin are similar in structure to trifluralin. Each of these herbicides is highly effective in controlling annual grass weeds but generally ineffective in controlling many large-seeded broadleaf weeds (16).

EPTC, a thiocarbamate applied as a preemergence, injected treatment, is effective in controlling some *Cyperus* species and certain other weed species (66,70). Care must be taken to avoid injecting this herbicide directly in the drill row because cotton will be injured.

Preemergence Treatments

Herbicide applications immediately after planting are an integral part of a successful weed management program in cotton. Applications may be made broadcast or as a band treatment over the drill row. Such applications are often coupled with the planting operation. Although considerable research has been directed toward developing herbicides that can be used as preemergence treatments in cotton, there are relatively few herbicides presently labeled in the United States.

Fluometuron and diuron are substituted urea herbicides that are widely used in the United States. Fluometuron is by far the most widely used, particularly in the southeastern states. It is effective on many of the more troublesome weeds of cotton such as *Xanthium* sp., *Ipomoea* sp. and *Cassia* sp. Fluometuron performance is generally consistent in the southern United States. Generally, the performance of this herbicide has not been as consistent in the western as in the eastern and central portions of the Cotton Belt.

Diuron, one of the first herbicides to be widely used in cotton, is still an important herbicide. Its performance has been less consistent at normal use rates than fluometuron in the Sough. Hamilton *et al.* (38) have reported that cotton varieties differed in tolerance to diuron.

In nutrient culture studies, Eshel (29) reported that diuron was considerably more phytotoxic to cotton than was fluometuron. Monuron, another substituted urea herbicide, is adapted for use only as preemergence treatment in heavy soils. It presently is used infrequently.

Prometryn, a methylthio *s*-triazine, is effective in controlling a number of weed species. Because performance is acceptable only on certain soils, prometryn is used to only a limited extent in cotton in the United States.

Alachlor and dipropetryn are used on certain soils of the Southern Great Plains. Occasional injury from alachlor has prevented its widespread use, particularly in the southeastern and midsouth cotton-growing regions. Dipropetryn has excellent crop tolerance on the sandy soils of the Texas High Plains.

Bensulide, DCPA, diphenamid, propachlor and norea have been labeled and used as preemergence treatments for weed control in cotton. With the possible exception of DCPA, these herbicides are not widely used at present.

Postemergence Treatments

Postemergence herbicide treatments may be initiated almost as soon as cotton is up to a stand. Applications are made over the top of the cotton or, more often, as a directed spray at the base of the cotton plants. The employment of directed spray enables the use of highly active herbicides for postemergence control of weeds. The most widely used herbicides applied as postemergence treatments are the organic arsenicals, MSMA and DSMA. These herbicides are active on a number of grass and broadleaf weed species and are particularly effective on the *Cyperus* species. MSMA is slightly more active than is DSMA on many weed species.

Directed applications of DSMA or MSMA are generally not injurious to cotton (7). Over-the-top applications to small (4-8 cm) cotton caused slight yield reductions in Arizona tests (3); a delay in application resulted in progressively greater reduction in yield and a delay in maturity. Seed cotton yields, boll weight, lint percentage, number of seed per boll and fiber fineness were related to the number and rate of application of these herbicides. Keeley and Thullen (51) noted that MSMA and DSMA were not as injurious to cotton at 31°C as at lower temperatures. DSMA is generally less injurious to cotton than is MSMA (3), although DSMA soil residues may injure subsequent crops. Growth of *Oryza sativa* L. in a Bosket silt loam was reduced 75 percent by 50 parts per million (ppm) of DSMA (63). This same concentration caused only 10 percent injury to cotton and no measurable injury to wheat (*Triticum sativum* Lam. var. Chancellor).

Fluometuron, prometryn, diuron and methazole may be included with one of the arsenicals to further increase foliar activity and for residual weed control. Methazole alone will effectively control *Sida spinosa* L. without injury to cotton, provided applications are made as directed sprays (19).

Late-applied postemergence herbicide treatments, often referred to as "lay-by" treatments, are used to provide late-season weed control. As pointed out earlier, such weed control measures are usually not necessary. However, if earlier weed control programs have not been effective or if stand of cotton is skippy, a lay-by application of herbicide may be necessary. Diuron, fluometuron, trifluralin, dinitramine, linuron, prometryn and DCPA are used as lay-by treatments. Application is usually made at time of last cultivation. The inclusion of a surface active agent will improve foliar activity if weeds are present at time of application.

Spot Treatments

Dalapon is used as a spot treatment for *S. halepense* control. Foy and Miller (30) showed that basal application of dalapon at 3.4 or 6.7 kg/ha during early square or full flowering caused no noticeable injury symptoms but delayed maturity and reduced yields in proportion to dosage.

Herbicide Combinations

Two or more herbicides are sometimes used simultaneously in combination mixtures or in sequence, often referred to as an "overlay", in order to increase the spectrum of weeds controlled or to improve the overall effectiveness of the herbicide treatment. At present, trifluralin preplant incorporated and fluometuron or diuron as a preemergence treatment are used throughout much of the U.S. cotton belt. McWorter (56) has pointed out that herbicide combinations are advantageous only where weed populations include at least one major weed resistant to each component of the dual treatment. There are some real disadvantages, such as cost of treatment, possibility of greater herbicide residue and compromise on best technique for applying herbicides. In herbicide combination studies in Alabama, most combination treatments were more consistent than a single herbicide (8). However, broadleaf weed control with fluometuron plus trifluralin was not better than fluometuron alone; grass control was only slightly better with the combination.

Combinations of trifluralin with linuron (5) and diuron (6) have been extensively evaluated under irrigated conditions. The linuron-trifluralin combination applied before harrowing controlled most grass and broadleaf weeds more effectively than did trifluralin alone. In later studies, a preplant incorporated application of trifluralin with a postemergence application of diuron gave effective weed control.

New Developments Affecting Cotton Weed Management

New Herbicides

Glyphosate has particularly good activity against perennial grass weeds such as *S. halepense* and *Cynodon dactylon* L. Pers. It has a major advantage in that it has no appreciable residual soil activity; therefore, cotton could be planted immediately after application. Glyphosate also has activity against other perennial weeds, such as *Solanum elaeagnifolium* Cav., which is becoming a major problem in cotton fields. Application of glyphosate must be made before cotton emerges in the spring, during a period when cotton is "off" such sites, or late in the season after cotton matures.

Two herbicides have been evaluated extensively and found to be active against *Cyperus* species (10). Norflurazon has given marginal to good control of both *Cyperus esculentus* L. and *C. rotundus* L. (49). *C. esculentus* L. emerged when treated with norflurazon but usually died within 2 to 4 weeks (50). In an extensive series of experiments with a number of cotton cultivars and norflurazon, we found that all cultivars that carried the 'glandless' genetic characteristic were susceptible to norflurazon injury (unpublished data). Phytotoxicity was as much as 95 percent with 2.5 kg/ha.

Perfluidone is extremely effective in control of *C. esculentus* L. (34). Although there are several similarities in response of cotton and *C. esculentus* L. to perfluidone, *C. esculentus* L. did not recover and resume normal growth when the herbicide was removed from the root environment in greenhouse studies (21). In contrast, cotton appeared to resume normal growth upon removal of the herbicide from the root environment.

Several dinitroaniline herbicides are currently under development. Profluralin has recently been approved for weed control in cotton. Butralin, fluchloralin and penoxalin are yet to be labeled. These herbicides are similar to other presently used dinitroanilines. The performance of dinitroaniline herbicides is similar. Activity against annual grass weeds is generally excellent. They also have good activity against many broadleaf weeds; however, several large-seeded broadleaf weeds, such as *Xanthium* sp., *Cassia* sp. and *Ipomoea* sp., are not controlled. The dinitroanilines require incorporation, usually within 24 hours after application. The rate requirement is generally similar to trifluralin with the exception that dinitramine requires slightly less and butralin slightly more herbicide for comparable weed control.

Tetrafluron, a substituted urea, has been extensively evaluated in different areas of the United States. This herbicide is active on a broad range of weed species.

Non-herbicide Weed Control

Considerable research effort is being expended in the development of an ultra high-frequency electromagnetic field (2450 ± 20 megahertz) for control of weeds and weed seed (22,68). Some weed species are highly susceptible, whereas others are relatively resistant to a given field intensity. This technique is of particular interest because of the low potential for residue problems.

Summary

Limitations in petroleum products demands that we continue the development of low-energy-requiring weed management techniques. Weed management programs that utilize crop rotations, field "sanitation," and competitiveness of the cotton plant are generally low in energy requirement. Efforts should be continued in the development of biological weed control techniques for major weed species.

Further development in management of weeds in cotton will rest heavily on improvements in management techniques. The cotton grower who can clearly define his problems and economically manipulate his weed management techniques will be the most successful cotton grower.

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BIOLOGICAL PRINCIPLES FOR THE RATIONAL USE OF PESTICIDES IN THE INTEGRATED CONTROL OF AGRICULTURAL PESTS

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Stringent and rigid requirements in terms of ecological, economical and health factors presently are being placed on methods of protecting plants from injurious organisms. These methods are designed to prevent the harmful effects of these organisms while simultaneously conserving all the useful natural elements of the animal and plant kingdoms and eliminating any negative effects of environmental pollution.

In developing the best plant protection programs, most countries try to select a biologically sound combination of efficient, environmentally harmless and economically rational control methods. At the present time there is a growing interest throughout the world in integrated programs which stress the use of methods and techniques that promote the utilization of natural, useful, biological agents which suppress harmful insects and mites. These programs for controlling pest abundance emphasize agricultural measures which reduce the losses caused by insects and mites. Great significance is attached to minimizing costs and to assessing the economy of natural and cultural methods for protection of the plants. An important role also is played by utilizing a series of biological and chemical control techniques.

It should be noted that the development of such programs and their practical implementation require a sound knowledge and understanding of a number of interconnected ecological indices. The determination of these involves, in many cases, extremely complex research in theoretical and applied ecology. Such indices are, inter alia, the determination of the losses caused by individual populations of pests in different eco-geographic zones, or the determination of the relation between the abundance of useful and harmful components of the agroecosystem and when active measures should be taken to protect the crop.

The problems concerning the economic soundness of the proposed integrated control system also may require exhaustive investigation over a long period of time.

For the reasons expounded above, and taking into account all ecological and economical factors, many integrated control systems still are in the developmental stage. Thus, the plant protection services of many countries use only individual control measures or combinations of measures in some integrated programs.

The practical experience of many countries, including the Soviet Union, unquestionably shows that in plant pest and disease control the measures most economically effective and the least harmful to the environment are prophylactic in nature. These may include certain agrotechnical techniques such as the use of varieties resistant to harmful pests.

In Soviet farming there are many examples of the successful suppression of the harmful activity of pests by means of various agricultural techniques. By correctly selecting the sowing time of cereal crops in their proper cropping areas, damage from *Chloropidae* can be prevented. Timely harvesting of small grain cereals makes it possible to reduce losses inflicted by *Eurygaster integriceps*, *Anisoplia*, *Cephus pygmaeus L.*, *Hadena sordida* and other pests. However, the nature of the farming system may not always allow the manager to follow the integrated control concept when suppressing pests and diseases.

Intensity and type of cultivation of certain agricultural crops may sometimes lead to the increased importance of certain pests. In such instances, the use of plant varieties resistant to diseases and pests, combined with the use of biological and chemical plant protection techniques, assume particular importance.

Many countries, including the U.S.S.R., have achieved specific successes in developing crop varieties that are resistant to pests. For many years loricate varieties of sunflowers have been grown on the huge territory of the U.S.S.R. These varieties are resistant to *Homoeosoma nebulella*, which in the past greatly reduced the yields of this valuable crop.

The famous Soviet academician, V. N. Remeslo, developed varieties of winter wheat (Mironovskaya 264 and 808) resistant to *Mayetiola destructor*. The large-scale introduction of these varieties has eliminated entirely the losses caused by this dangerous insect in the forest-steppe zone of the European U.S.S.R. The growing of these varieties has also made it possible to reduce drastically the use of chemical pesticides needed on wheat. In addition, corn varieties have been developed that are resistant to *Pyrausta nubilalis* and *Oscinosoma frit*.

During the last 10 years biological pest control methods have undergone great development in the U.S.S.R. In 1974, predator and parasitic insects and mites, as well as certain biological preparations, were successfully introduced on an area in excess of 8 million hectares. Despite considerable difficulties, there is no doubt that use of natural agents for the protection of plants will continue to be developed and expanded on a practical basis. Nevertheless, at the present time the number of pests in the U.S.S.R. that can be successfully controlled by biological methods is relatively small.

The great variety of harmful insects and mites feeding on the same crop, and the undeveloped condition of biological and other nonchemical suppression methods require that chemical control procedures be included as one of the most important components in most contemporary integrated control programs. This is completely justified because, despite the peculiar properties of the biological and chemical methods, more and more information is being gathered concerning possible ways and methods for combining biological and chemical pest control methods.

During the past 50 years, chemical pest control methods have been increasingly used in the U.S.S.R. The greatest expansion occurred after 1960, when the use of insecticides and fungicides increased from 48,900 tons (active ingredients) in 1960 to 281,000 tons in 1973. This was a result of mastering the production and use of new organic synthetic pesticides. This resulted in an increased volume of use and a radical change in the assortment of insecticide and acaricide formulations available for farm use.

As the practical application of insecticides and acaricides increased (including, in many cases, the spraying of crops from planting to harvest), the danger of poisoning humans, domestic and wild animals and beneficial insects like bees also increased. The increased use of pesticides also increased the danger of contaminating crops and the environment with residues of cumulative, environmentally persistent chemicals.

During the past 10 years the U.S.S.R., as well as many other countries, has promulgated considerably stricter regulations for the use of insecticides and other pesticides than were previously in effect. At the same time, attention has been directed to determining bioecological aspects for the rational use of pesticides for crop protection and for their use in combination with other pest suppression methods within the framework of integrated control. It must be assumed that the progressive expansion of chemical pest control methods is associated to a considerable degree with the continuing increase in the number of compounds available and the improvement of pesticide application methods. This has been dictated by sanitary and health requirements and by changes occurring among the pests themselves--specifically the appearance of arthropod populations that have become resistant to pesticides.

The inclusion of certain chemical compounds as an element of integrated control must be preceded by a comprehensive evaluation on the basis of sanitary and health factors. This must include both the acute and chronical toxicity of the compounds to warm-blooded animals, including man, and their mutagenic, teratogenic, carcinogenic and other properties. In the U.S.S.R., scientific and manufacturing agencies of the

Ministry of Health are implementing regulations for pesticide safety standards. In consideration of the requirements for the selective action of insecticides and their potential harm to the environment, the use of formulations of arsenic, parathion, demeton and DDT have been prohibited in the U.S.S.R.

Of growing importance in selection of chemicals for use in integrated systems is their effect on entomophagi. Among the new insecticides, selective compounds have been discovered which, while destroying the pests, do not destroy entomophagous species. Specifically, the use of Bayfos is recommended for control of certain aphids. This insecticide has a very high intravegetative and contact activity and a long-lasting effect on various species of aphids but is totally harmless to various species of *Coccinellidae* and bees. The compound Amiphos has the same properties.

By including insecticides such as these into complex pest control systems it becomes possible to drastically reduce the adverse impact of pesticides on the environment. However, a great number of insecticides exhibit high biological activity to the insect natural enemies that reside in the crops to be protected.

Investigations, conducted in the U.S.S.R. by the All-Union Institute for Plant Protection, on the toxicity of present-day insecticides for entomophagous species from various taxonomic groups have revealed a high sensitivity to insecticides of entomophagi such as *Trichogrammatidae*, *Coccinellidae* and *Miridae*.

In their effect on the adult of the useful insects mentioned above, the experimentally tested insecticides can be divided into three groups: (1) highly toxic--carbaryl, trichlorfon, phtalophos, dimethoate, Nexion (LK$_{50}$ 0.0001-0.008 percent); (2) moderately toxic--Bayfos, meta-systox (LK$_{50}$ 0.02-0.19 percent); and (3) lightly toxic or nontoxic--Akrex, Milbex, Lethane, Neoron (LK$_{50}$ 0.3-1 percent).

Chrysopa carnea is naturally immune to most of the tested compounds, especially at the larval stage (LK$_{50}$ 0.02-1.0 percent). This is also true for *Nabidae* and *Lygaeidae*. Some *Coccinellidae (Stethorus)* also have been discovered to be pesticide-resistant.

Analysis of toxicity data of pesticides for phyto- and entomophagous species leads to the assumption that specific formulations (acaricides and the aphicide Bayfos) exhibit a different degree of selectivity in their effect on beneficial insects and are totally harmless to most of them (the selectivity coefficient is 10-1,000).

Formulations having a wide range of action also have revealed a considerable degree of selectivity in tests with a number of entomophagi. It is believed that in integrated programs, along with selective insecticides, compounds having a broad spectrum of activity may be used after their biological activity has been studied sufficiently.

The first principle in the rational use of broad spectrum insecticides that should be considered is the possibility of selective chemical control which would provide maximum conservation and efficiency of entomophagous species and which would inflict great mortality on the pests at a time when the beneficial organisms are not in a vulnerable developmental stage.

Consideration should be given to a method for preliminary reduction in the abundance of injurious insects by using pesticides which are least harmful to the entomophagous species. This method can change the abundance ratio in favor of the beneficial species. Thus, we pursue the objective of timing the application of plant protection chemicals so as to avoid the periods of maximum activity of adult entomophagous species. In the U.S.S.R. positive data are available concerning the conservation of natural enemies of forest pests--*Porthetria dispar*, *Dendrolimus pini*, *Tortrix viridana* and other insects whose caterpillars appear 10-15 days before the first flight of the adult parasite-insects. As a result, it has been proven in subsequent years of high entomophagi abundance that it is possible to have partial chemical treatment of an area, depending upon the activity of the conserved parasite and predators in the areas not subjected to treatment.

The problem of conserving insect natural enemies becomes quite complicated in the case of chemical control of pests of agricultural crops, the cultivation of which leads to a reduced stability of the agroecosystem. In the cropping system the complex of injurious species that harm a specific crop includes those with different systematic positions and with different seasonal development cycles. The interrelationship between injurious and entomophagous species may noticeably change in the course of a season, depending upon ecological conditions.

Parasitic insects that overwinter in a host frequently emerge in the spring after the host dies. This has been established in the U.S.S.R. for parasites of *Hylemya brassicae*--*Trybliographa rapae* West., and *Mayetiola destructor*. Predatory *Coccinellidae* and *Carabidae* usually become more numerous in the habitats of their prey after there has been a noticeable increase in prey abundance. Some parasites, not associated with hosts during hibernation, may appear in the spring before the hosts emerge. As a rule, *Trissolcus grandis*, a parasite of the eggs of *Eurygaster integriceps*, emerge from the wintering habitat 10-15 days before the host insect lays eggs in the wheat fields.

Consideration of this ecological fact has made it possible to better plan the chemical control of *Eurygaster integriceps*, which is very abundant in the U.S.S.R. Not long ago, two chemical treatment periods were used on wheat fields in certain areas of the U.S.S.R. to control *E. integriceps*. This resulted in mass destruction of its parasites. Shifting the period of insecticide treatments to coincide with the growth period of the pest larvae turned out to be harmless to the parasites. The scientists of the All-Union Plant Protection Institute also have learned that this procedure conserves the abundance of the parasites.

In order to obtain the best combination of chemical pest control and conservation of natural enemies, it is extremely important to determine the developmental stages of the entomophagous species which are most resistant to pesticides. Investigations in the U.S.S.R. and other countries have revealed that there is a noticeable change in the sensitivity to pesticides of these species during their ontogenetic development.

Insecticides have a weaker effect on pre-imago phases of egg parasites, which are usually reliably protected by the chorion of the egg of the insect host. However, even in such groups developmental phases have been detected in the U.S.S.R. which are less resistant to insecticides. Thus, on pre-imago phases of *Trichogrammatidae*, the greatest damage produced by organophosphorous insecticides is to the pupae and especially to the adult before the emergence.

Telenomus also shows the greatest sensitivity to certain insecticides during the pupal stage. Investigations have established that the toxic effects of the insecticides on the pupae of *Telenomus* increases proportionately with the mechanical damage inflected by the growing parasite to the surrounding host egg shell. A high rate of survival has been observed in parasites of *Aphididae* and *Coccidae* that complete their development in mummified bodies of their hosts. The rigid external shell of the mummy apparently protects the parasite from the harmful effects of the pesticide.

By taking into consideration the developmental stages of pest parasites and predators that are most resistant to insecticides, we can determine the best timing for applying insecticides so that they inflict the least damage to the entomophagous species. Such a possibility was established by applying chemical pesticides against the first generation of *Pieris brassicae* and *Plutella cruciferarum*. Simultaneous conservation of a considerable number of entomophagous species and destruction of pests may be achieved by applying chemical pest control during the period of early appearance of caterpillars of older *Pieris brassicae*. This coincides in time with the transition of a large number of *Apanteles glomeratus* (a parasite of *Pieris*) and *Chorogenes* (an enemy of *Plutella*) into the last stage and the one that is most resistant to pesticides.

Consideration of the above-mentioned ecological relations in the ecosystem of the crop to be protected produces a situation ideal for the biologically justified use of pesticides.

For strict regulation and justified use of pesticides in integrated programs it is extremely important to establish pest abundance levels or economic injury thresholds for insects and mites at which the application of chemical control measures is justified both ecologically and economically (Table 1). At the present time a number of institutions in the U.S.S.R. are engaged in carrying out investigations to determine these criteria. For some pests these criteria have already been established, and the Operations Service of the U.S.S.R. Plant Protection Institute is putting them into practice. This paper refers to some of them.

By taking into account the established abundance level it is possible to replace total chemical pest control of the crop with selective treatments. This makes the insecticide control more economical and more importantly, the negative effects of the pesticide on the agroecosystem are lessened. In Tadzhikistan, for instance, the change from total chemical control of cotton against *Heliothis obsoleta* to selective control (8-12 caterpillars per 100 plants) has resulted in a considerable increase in the abundance of entomophagous species in the area.

The effectiveness of chemical control may be greatly increased and its negative consequences reduced by resorting to more rational types of insecticides and formulations and selective methods of application. Some success has been achieved in developing a theory and a technique for use of granulated insecticides and a combination of chemicals for protection of seed. For many crops, headland treatment with insecticides, as well as hill placement of insecticides, have produced excellent results.

However, there is great need to continuously revise and improve the assortment of insecticides for the reasons already expounded and because of certain consequences that have been brought about in the populations of the pests themselves following massive treatments with chemical compounds. One such consequence has been the development of strains of insects and mites resistant to insecticides. Especially dangerous for the U.S.S.R. is the fact that *Tetranychus telarius* has become resistant to organophosphorous preparations and that some mites have become immune to soil treatments of chemicals.

The system of integrated pest control, which utilises a minimum number of insecticide treatments and provides for a rotation of compounds from various chemical classes, provides a reliable means for minimising many of the of undesirable side effects of the use of chemicals in plant protection. In this case it is possible to delay and prevent the development of cross-resistance of pests to pesticides.

Table 1. Abundance levels of the principal agricultural pests at which the initiation of chemical pest control measures is recommended.

Crop and pest	Economic harmfulness threshold
Cereal crops:	
1. *Eurygaster integriceps*	
Overwintered bugs	
on winter wheat	2 specimens per 1 square meter (m)
on spring wheat	1.5 specimens per 1 square m
Larvae	
on winter wheat	2 specimens per 1 square m
on spring wheat	1 specimen per 1 square m
on barley	3-5 specimens per 1 square m
2. *Hadena sordida*	
on wheat	20 caterpillars per 100 heads
3. *Oscinosoma frit*	
on wheat	6 larvae per 100 stems
4. *Mayetiola destructor*	1-6 puparia per stem
5. *Agrotis segetum*	3-8 caterpillars per 1 square m
6. *Cephus pygmaeus L.*	
on corn	4 imagini per 1 square m or 32 larvae
7. *Oscinosoma frit*	6 larvae per 10 plants or 1-2 larvae per plant at 2-3 leaf stage
8. *Pyrausta nubilalis*	
on sugar beets	17-18 percent of plants infested with eggs
9. *Bothynoderes punctiventris*	0.1-0.5 overwintered beetles per 1 square m
10. *Chaetocnema breviuscula*	
on cotton	2-7 specimens per 1 square m
11. *Heliothis obsoleta*	10 larvae per 100 plants 5 larvae per 100 plants of fine-fibered varieties
12. *Tetranychus telarius*	
on flax	15 mites per 100 leaves
13. *Aphthona euphorbiae*	
on fruit crops	10-15 specimens per 1 square m
14. *Laspeyresia pomonella*	2-3 eggs per 100 fruit
15. Tetranychidae	2-5 mites per leaf

An extremely promising component of integrated pest control is the use of pest-resistant crop varieties. This may allow us to reduce the concentration and dosage of pesticides used for plant protection.

In some countries potato varieties are being grown that are resistant to potato nematodes. The growing of these varieties of potatoes allows the amounts of nematicides used to be reduced. This helps considerably in devising a more rational means of plant protection. Similar data also are available in the U.S.S.R.

With many pests, it has been found efficient to use microbial biocides with reduced doses of insecticides. The combining of a preparation of entobacterin with only 0.015-0.02 percent of an insecticide (Chlorophos or carbaryl) has greatly increased the effectiveness of chemical control measures used in the Ukraine and in Moldavia to combat orchard pests.

Recently, chemicals of a new nature, the so-called "third generation pesticides" have been used. These are hormonal preparations (or their analogues), insect sterilants, attractants and repellants. All these preparations are characterized by an increased selectivity of action. Their application may make it possible to control a number of pests while at the same time preserving beneficial species. The use of these preparations must be based on a scientifically established economic threshold for the pests, an operative recognition of the correct periods during which to apply pest control measures, consideration of economical factors and the actual effectiveness of the measures to be introduced.

As the integration of control methods becomes the basic trend in successful protection of agricultural plants and crops from pests, the ecological and economic aspects of utilizing chemicals in integrated programs of pest control must be established scientifically.

COTTON WILT CONTROL THROUGH BREEDING - A PERSPECTIVE

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Among soil-borne, fungal diseases of cotton, Verticillium wilt is of foremost economical importance and well known both in the United States and in the Soviet Union. In both countries Verticillium wilt has been recognized as a serious disease since the 1920's. It is caused by the microsclerotial form of *Verticillium albo-atrum*, called *V. dahliae* by some authors.

In the United States, Verticillium wilt is most devastating to cotton in the arid Southwest, including California, where rainfall occurs only during winter and spring, and dry summers make irrigation essential to successful cotton cultivation. These climatic conditions are also common to the central Asian province of Uzbekistan, where much of the cotton of the Soviet Union is grown, also completely under irrigation.

New Soviet Cottons

Without question, the new Tashkent varieties developed by Sadyek M. Mirakhmedov, especially Tashkent-1, have solved for the present the cotton wilt problem in much of the Soviet Union (3,4). Around Tashkent, where the All-Union Cotton Research Institute is located, the major, perhaps the only, variety now grown is Tashkent-1. The few fields of Tashkent-1 there that the author was able to visit recently showed no evidence of Verticillium wilt; the boll load was heavy, and an anticipated yield of approximately 4,400 kg seed cotton per hectare (2-1/4 bales per acre) was realistic. In one field of a variety apparently other than a Tashkent, however, in the vicinity of Samarkand, it was noted that wilt was pronounced, with symptoms including both defoliation and vascular discoloration.

The source of wilt resistance for the Tashkent varieties was *Gossypium mexicanum*, properly *G. hirsutum* subsp. *mexicanum* var. *nervosum*, a perennial, brown-fibered, wild Mexican cotton of no economic importance. Nadeshda N. Guseva (now Chief of the Laboratory of Plant Disease Immunity of the All-Union Research Institute for Plant Protection, Leningrad) in 1968 was first to report the wilt resistance of this species. In studies in California Guseva's findings have been confirmed (5), but the varieties Tashkent-1, -2 and -3 were found unusually wilt-susceptible (6). In Uzbekistan traces of "Mexican" characters were clearly evident in the Tashkent-1 variety--namely, small yellow flowers, prominent red venation and typical upward-cupping of the thick, leathery leaves with three prominent lobes. Also, as remarked by entomologist Ray Smith, the plants were remarkably free of insect pests.

The success of Soviet scientists in creating the Tashkent varieties marks a milestone in the long history of cotton improvement; it also prompted a further search among wild races of *G. hirsutum* for resistance to wilt. Among the many accessions acquired from worldwide sources, both wilt-susceptible and wilt-resistant individuals have been identified. Aliesh Haley, in her PhD thesis research, has also found high resistance in *G. hirsutum* race *marie-galante* and race *latifolium*. Race *marie-galante* is of particular interest because of its history as a cultivated cotton in the Antilles during the 18th century, its excellent, long, pure white fiber, its unusually deep rooting habit and the readiness with which it hybridizes with Upland cottons to yield fertile offspring.

Two factors considerably complicate the problem of Verticillium wilt control through breeding: (1) the wild forms of *G. hirsutum*, as well as the old, outdated varieties, and the present cultivars all are susceptible to root invasion and colonization of the vascular system of the main and branch stems by *Verticillium*, regardless of whether symptoms develop and (2) the maximum symptom development usually occurs during the maturity phase of plant growth, thus making accurate symptom evaluation difficult. At that time, in addition to causing terminal shoot dieback and boll shedding, *Verticillium* and possibly other fungi may cause the death of cotton rootlets, resulting in rapid collapse of the plant (unpublished data of Lester W. Burgess). In California, these severe symptoms generally appear in early September, 1 to 2 weeks after the last irrigation.

Plant Phenotype and Wilt Resistance

In 1950, Leyendecker in New Mexico presented evidence that cultural practices, which included close spacing of cotton plants in the row, may reduce severity of Verticillium wilt. He showed that disease severity in a field depends not only upon the resistance potential of a variety and upon how favorable the environment is to symptom expression, but also upon the spacing of plants in the row (2). In narrow-row culture studies, Alan George has confirmed this significant discovery under California conditions (1). His studies also pointed to the fact that close spacing demands a special plant-type, capable of setting bolls early in the season under crowded conditions.

In the course of 11 years of investigation wilt resistant plant types which develop 10 to 12 short lateral branches over the entire length of the main shoot and bear usually one boll per branch have been selected from hybrid lines and accessions. These are not cluster types. As the plant approaches maturity, it bends nearly to the ground by the weight of the green bolls. At maturity, as the bolls open the plant, which is technically arched rather than lodged, becomes erect again. The bending to the ground appears to have the effect of girdling the plant at the ground line, thus aiding boll maturity to the apex of the main stem. Experimental lines of this plant type have given test yields of nearly 2 bales of lint per acre (1000 kg per hectare). Plant populations were 60,000 to 80,000 plants per acre, resulting in a distance of 2 to 3 inches (5.0 to 7.5 cm) between plants in the row, with rows 38 inches (95 cm) apart.

These lines are all infected by the *Verticillium* fungus to the point of extensive colonization of vascular tissues of the main stem, but when grown at close spacing in the row, they suffer only minimal yield losses due to disease.

The Multiline Cultivar Concept

National agencies have warned that the genetic bases of our major crops, including cotton, are narrow and becoming narrower as crop improvement aimed at high yields continues, and it now appears that a key to wilt control in cotton may lie in significant genetic diversity. Highly wilt-resistant lines, such as were obtained from the interspecific cross *G. barbadense* X *G. hirsutum*, when crossed together yield predominantly wilt-resistant offspring, with the F_1 showing resistance equal or superior to that of the parents and the F_2 and subsequent generations somewhat variable but still mostly resistant (7). It appears that in such multiline cultivars, parent combinations can be achieved to incorporate resistance and agronomically valuable characters. Useful parents, once identified, must then be maintained as clones by vegetative propagation, and the crosses, as the starting point for seed production, must be repeated every year. If five cloned parents, for instance, were crossed in all possible combinations, commercial planting seed could be available in the fourth or fifth year after the crosses were made. The variability of cultivars derived in this way rather than by selection and increase from individual plants would present barriers to the rapid development and spread of new strains of the Verticillium wilt fungus. The soundness and practicability of this concept has been demonstrated experimentally. High-yielding lines in University of California research this year will be the wilt-resistant F_2 populations of select parents derived from the interspecific cross *G. barbadense* X *G. hirsutum*. The greatest difficulty encountered in these lines is lateness of maturity, a character imparted by the *G. barbadense* parent.

Possibility of Immunity to Wilt

In the many varieties, wild types and species of cotton that have been studied to date growing under field conditions, *Verticillium* infection has always been detectable in vascular tissues of the main stem, regardless of whether the plant showed wilt symptoms; thus the view developed that no cotton was immune to vascular infection.

However, in a unique instance of transgressive segregation in a cross involving two different lines of *G. barbadense*, a single plant was found that appeared to be immune. Repeated culturing of stem tissues throughout the growing season failed to show the presence of the *Verticillium* fungus. Through hybridization with Rex, an early-maturing Upland cotton from Georgia, earliness and compact habit was incorporated into this line without losing the immunity. Other than in habit, the plant still shows the phenotypical characters of *G. barbadense*. Other hybrids with this interesting material have now been grown and are retaining only immune individuals or those approaching maturity.

The goal of wilt-immune cotton cultivars, though perhaps only a plant pathologist's dream, obviously has much in its favor. It is rather certain that any wilt-tolerant or wilt-resistant, but nevertheless infected, cotton cultivar will eventually collapse from wilt and thus have only a relatively short usefulness. This is due either to acquisition of new specific pathogenicity by the *Verticillium* fungus or to seasonal environmental changes which favor symptom expression. Possibly the infected plant even "directs" the selection process for intensification of new pathogenic strains of the fungus.

If cotton production is to remain viable in California, and also in other wilt infested areas, the best possible advantage must be taken of the available resistance, such as using it in multiline cultivars and combining it with phenotypes that set bolls early under crowded conditions in the row.

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Microbial Insecticides

A REVIEW OF RECENT ACTIVITIES (1974-75) IN THE DEVELOPMENT OF MICROBIAL INSECTICIDES IN THE UNITED STATES

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Current Status

The research and development of microbial insecticides in the United States began in the 1930's with the bacterium, *Bacillus popilliae*, for the control of *Popillia japonica*. This was followed by commercialization of the bacterium, *B. thuringiensis* (Bt), in 1958. During the past decade research activities have focused on developing the use of selected baculoviruses such as *Heliothis* nuclear polyhedrosis virus (NPV), *Porthetria* NPV, *Hemerocampa* NPV and, most recently, *Autographa* NPV.

Microbial insecticides are products containing insect pathogens that are applied as needed to suppress pest populations. If an application results in an epizootic or long-term control of a pest, these are fringe benefits. Interest in developing microbial insecticides has been stimulated mainly because (1) they are generally considered to be selective, environmentally non-disruptive control agents ideally suited for use in integrated control and other types of pest management programs; (2) they can aid in the control of pests that are resistant to chemicals; (3) they can provide relief in situations where the use of effective chemical pesticides is restricted by law; and (4) through their use, heavy reliance on chemical pesticides can be reduced.

In Table 1 are shown many of the insect pathogens currently receiving attention as microbial insecticides in the United States. Twenty-three agents are listed in four groups: 3 bacteria, 7 viruses, 8 fungi and 5 protozoa. Commercial products are indicated by trade name and manufacturer. The general area of research activity is listed with numbers referring to researchers active in the area. These are listed by number at the bottom of Table 1 at the end of the paper.

A recent major event in microbial insecticide research was the reported attenuation of *Bacillus popilliae* spores in soils where the bacterium has been present over 30 years (3).[1] *B. thuringiensis* (Bt) has continued to receive much attention, as it is a dynamic pathogen with new strains continuously being developed (4). Concurrently, industry has developed better formulations and more stable products that are more effective and simpler to use. Researchers are constantly expanding the effective host range and utility of Bt products. Currently, Bt is registered for the control of more than 30 species of Lepidoptera on more than 30 crops and other plants. The consumption of Bt is rising as more restrictions are placed on the use of hard pesticides, the demand for organically grown food increases and better Bt products are made available.

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[1] Numbers in parentheses refer to researchers listed in Table 1 who are working in areas indicated.

B. sphaericus has stimulated much interest of late because of its effectiveness in suppressing larval populations of malaria vectors *Anopheles* sp., *Culex pipiens* and *Aedes aegypti* (9,10,11). This bacterium appears to be a good candidate for industrialization.

One of the most important activities of recent years has been the industrialization and commercialization of *Heliothis* NPV. More than 10 years have gone into this effort, with current emphasis on the improvement of efficacy through formulation and application technology. This activity began with demonstrations that commercial preparations of *Heliothis* NPV deposited on cotton foliage degrade rapidly (12,13). Efforts to stabilize *Heliothis* NPV against sunlight inactivation resulted in the development of several formulations that significantly slowed the loss of viral activity (5,6,7). Good worm control has been reported with *Heliothis* NPV applied in cottonseed oil bait (13); doubling the volume of spray per acre (6); and ultralow-volume (ULV) micro-droplet application of *Heliothis* NPV suspended in unrefined cottonseed oil (5). Moths which were fed *Heliothis* NPV produced contaminated eggs which resulted in infected larvae (42). *Heliothis* NPV dust was effectively disseminated in the field via the autocontamination of wild moths (5).

Much has been learned about the population dynamics and population regulation of *H. zea*. Through systems analysis and modeling, various programs are available to forecast the appearance and possible magnitude of bollworm populations. Also, cotton plant model programs have been developed and utilized to identify the critical stages of plant growth, fruit development and maturation and to assess the effects of bollworm and other pest attacks. The systems analysis and modeling information, along with the various approaches to the application of *Heliothis* NPV, are also being applied to the development of *Autographa* NPV, *Laspeyresia* GV, commercial formulations of Bt and other insect pathogens (5).

Autographa NPV is an interesting virus because of its apparent wide host range. It reportedly infects species in several genera in the Lepidoptera including *Bucculatrix*, *Estigmene*, *Heliothis*, *Pectinophora*, *Plutella*, *Spodoptera* and *Trichoplusia* (15). This virus is currently receiving increasing attention from researchers (5,6,12,15,16), and the industrialization potential is considered excellent.

Porthetria NPV and *Hemerocampa* NPV are being developed by the Forest Service of the U. S. Department of Agriculture. Efforts are being made to develop the information required for registration of *Porthetria* NPV (17,18) and *Hemerocampa* NPV.

Although granulosis viruses are considered to have a high industrialization potential, research activity is much reduced at this time. As for noninclusion virus, fungi and protozoa, none appear to be close to registration, although there is some interesting research underway. In the United States the future appears to be with the baculoviruses and especially the NPV's.

Factors Influencing Development of Microbial Insecticides

Over 25 countries are known to have national pesticide laws, and in general, the basic principles employed are similar. In the United States, all pesticides are registered under the Federal Insecticide Fungicide and Rodenticide Act (FIFRA), and the Environmental Protection Agency (EPA) is responsible for pesticide regulatory functions. The requirements for the registration of biological pesticides are essentially the same as those prescribed for chemical products, that is, for registration purposes there must be clear and convincing evidence that the product to be marketed is effective as stated by the label and is safe when so used. The EPA has been granted broad and flexible authority to regulate the supply and use of pesticides in order to avoid any unreasonable risk to humans or the environment, taking into account the economic, social and environmental costs and benefits of the use of any pesticide.

A principal deterrent to the registration of any pesticide and especially microbial insecticides is the cost factor. Recent estimates have shown that research and development of a viral insecticide in the United States may cost in excess of $6.5 million (4). For private industry to function in this area, it must have a way to recoup its investments. The chemical pesticide industry does this through the patent system. The patent system, however, cannot be utilized as extensively with microbial agents because the U.S. Patent Office generally adheres to the principle that naturally occurring insect pathogens are not patentable. Thus, there is little legal protection for private companies developing and producing microbial insecticides.

It is obvious that private industry alone cannot afford to develop microbial insecticides. Federal and state research agencies and the state universities must be involved for this to happen. These groups need to be supported by public funds and industrial grants to accomplish the task. The research and development costs for safety evaluation and the basic efficacy testing must be supported heavily by public funds.

Some progress is already being made in this direction. An example of this type of activity is a forest pest management program involving the Forest Service of the USDA and state universities. It covers three pests: *Hemerocampa pseudotsugata*, *Dendroctonus frontalis* and *Porthetria dispar*. Some of the many objectives of this program are to conduct pilot field tests with the *Hemerocampa* NPV and safety and efficacy tests to evaluate and support the registration of *Porthetria* NPV.

More recently, a *Baculovirus Research, Development and Registration Program* was organized through the EPA, USDA and state universities. The principal objective of this organization is to aid, accelerate and otherwise promote the registration of selected baculoviruses determined to be safe, effective and useful for pest control. Initially, major emphasis has been placed on four baculoviruses: *Heliothis* NPV, *Autographa* NPV, *Porthetria* NPV and *Hemerocampa* NPV.

This program will focus on (1) virus identification and safety, (2) human monitoring, (3) environmental monitoring, (4) determining efficacy and usefulness, and (5) registration of selected baculoviruses. The organization consists of 3 sections: (1) safety (44,45), (2) efficacy (5), and (3) production (15) and a coordinator (43). It is expected that this program will provide a model for the future registration of all types of microbial insecticides. Consequently, registration and industrialization of most potentially useful microbial insecticides may depend on the success of the baculovirus program. Thus, while microbial insecticides are urgently needed for pest control purposes, much effort, money, patience and time will be required before more than the few already registered can be expected to become available.

Table 1. Commercial and experimental microbial control agents and current research activity

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(Numbers in brackets refer to researchers working in areas indicated and these are listed below.)

1. Bacteria
   1.1 *Bacillus popilliae*
      Doom® Fairfax Biological Laboratory, Clinton Corners, New York
      = metabolism/biochemical(1); production(2); attenuation(3)
   1.2 *B. thuringiensis* (Bt)
      Biotrol® Nutrilite Inc., Buena Park, California
      Dipel® Abbott Laboratories, North Chicago, Illinois
      Thuricide® Sandoz, Inc., Homestead, Florida
      = strains(4); application/formulation/persistence(5)(6)(7)(8)(41)
   1.3 *B. sphaericus*
      = pathogenicity(9)(10)(11); strains(10)

2. Viruses
   2.1 Baculovirus
      2.1.1 *Nuclear Polyhedrosis Virus (NPV)*
      **Heliothis* Elcar® Sandoz, Inc.; Biotrol® Nutrilite Inc.
      = application/formulation/persistence(5)(6)(12)(13)(42)(46); tissue culture(6)(14)
      **Autographa* = characterization(44); pathogenicity/host range/efficacy(5)(6)(12)(15)(16); tissue culture(6)(14)
      **Porthetria* = characterization(17); efficacy(18); tissue culture(17)
      **Hemerocampa* = pathogenicity/application/efficacy(7)(19)

      2.1.2 *Granulosis Virus (GV)*
      Laspeyresia pomonella = pathogenicity/application/efficacy(5)(20)
      Plodia interpunctella = pathogenicity/application/efficacy(21)(22)

   2.2 Non-inclusion Virus (NIV)
      Panonychus citri = pathogenicity/application/efficacy(23)

3. Fungi
   3.1 Phycomycetes
      3.1.1 *Coelomomyces spp.* (Culicidae) = production(24); pathogenicity/host range/efficacy(24)(25)

      3.1.2 *Entomophthora gammae* (*Pseudoplusia includens* = Soya) = host range(26)
      E. thaxteriana (*Myzus persicae*) = production/efficacy/host range(27)

   3.2 Fungi Imperfecti
      3.2.1 *Beauveria bassiana* (*Curculio caryae* = soil) = production/pathogenicity(28)
      (Psychidae) = efficacy(29)

      3.2.2 **Hirsutella thompsonii* (*Panonychus citri*) = efficacy/formulation/persistence(30)

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* Registration efforts in progress

3.2.3 *Metarrhizium anisopliae* (Culicidae) = application/formulation/efficacy(24)
(*Curculio caryae* = soil) = production/pathogenicity(28)

3.2.4 *Paecilomyces farinosus* (Noctuidae = Soya) = pathogenicity/host range/production(31)

3.2.5 *Nomuraea rileyi* (Noctuidae = Soya) = culture(32); efficacy/persistence(6)(33)

4. Protozoa
    4.1 *Mattesia spp.* (stored products) = efficacy(34)(35)
    4.2 *Nosema algerae* (*Anopheles spp.*) = production/pathogenicity/efficacy(36)
        **N. locustae* (Orthoptera = locust) = production/formulation/efficacy(37)
    4.3 *Perezia hyperae* (*Hypera postica*) = pathogenicity/persistence(38)
        P. pyraustae (*Ostrinia nubilalis*) = pathogenicity(39); production/formulation(40)

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THE PRESENT STATUS AND FUTURE OUTLOOK FOR BIOLOGICAL CONTROL OF ARTHROPOD PESTS OF VEGETABLE AND FRUIT CROPS IN THE U.S.S.R.

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The relationship between fauna and biocenosis in fruit and vegetable growing has been thoroughly studied. Our data show that the number of species of useful insects, ticks, spiders and birds significantly outnumber the harmful species.

Research on biological control has been carried out in the direction of using arthropod natural enemies and microorganisms for pest control. Presently, as far as entomophagous species are concerned, the following objectives are being pursued: (1) preservation of natural populations, (2) attraction of natural enemies to the crops to be protected, (3) induced dispersal of beneficial species within the crop and (4) seasonal colonization of the natural enemies.

Notwithstanding the great diversity of harmful species in the primary fruit-growing zones, the leading production areas and the established acreages in each region usually are inhabited by 10 to 15 species. In fruit-growing areas, more than 600 species of harmful insects, mites and nematodes have been observed.

Predatory and parasitic insects play an important role in suppressing the numbers of insect pests that prey on vegetable and fruit crops. For example, they destroy about half of the vegetable pest populations during the middle of the growing season.

The selective use of pesticides and the timing of their use are equivalent in their effects on a large number of entomophagous species. For example, research has shown that a single dusting with 2.5-percent metaphos by tractor during the middle of the summer to control *Acyrthosiphon pisum* Harr. may destroy in one hectare of vegetable peas 6-12 kg of beneficial insects, mainly the Carabidae, Staphilinidae, Coccinellidae, Syrphidae and others. However, if a spray of metaphos combined with vertoleta is used during this same period, the treatment destroys the aphids but practically conserves the beneficial insects.

As a result of the intensive use of insecticides on large industrialized farms, the activity of almost all arthropod natural enemies has been suppressed. As a consequence, steady and high rates of damage have been inflicted by such pests as *Laspeyresia pomonella* L., *[illegible] rediorsana* Heck, *Tetranychus viennensis* Zacher, *Eriosoma lanigerum* Hausm., *Lithocolletis corylifoliella* Haw., *L. pyrifoliella* and several others.

An expedient limitation of the insecticide treatment of truck gardens has resulted in an increased abundance and conservation of beneficial insects. To achieve this, a number of measures have been widely used, chief among which is a correct cropping pattern in the types and varieties of plants grown. This makes it possible to selectively carry out chemical treatments by the use of powerful air-blower-type machinery. The reduced amount of insecticides needed makes it possible to establish a crop-planting pattern on truck farms that will appropriately concentrate predators. Also, the necessary cultivation may be made without affecting the faunal populations of the entire farming area.

A large part of the protection of entomophagous species is obtained by the integration of several methods. This includes the advantageous use of parasites and predators during the periods of the hatching of crop-eating caterpillars, appropriate utilization of the adult stages of the parasites and keeping abreast of the activity of the adult stages of the various predators and parasites. The use of insecticides is based on observations of the numbers of predators and other entomophagous species and their survival during periods of cultivation. This can be used to afford protection to the entomophagous species.

It also has been established that the destruction of predators by toxic chemicals while still in the pupal stage is significantly greater than during the larval stage and higher than in the adult stage. For example, if the first chemical treatment against *Psylla pyri* L. is applied during the formation of the pupa, it is possible to dispense with the later three treatments in the same years, and the need for first or second treatments are sometimes postponed until the following year. At a location harboring *Eriosoma lanigerum*, three chemical treatments were carried out against the mummies and an additional one was made in August against an infestation of *Aphelinus mali* Haldeman. This produced a reduction in pest numbers of 83 percent, whereas usual treatments were only 4.2 percent effective.

Insecticide treatments made for control of *Yponomeuta malinellus* and *Y. padella* at a time when there is a moderate number of caterpillars and carried out while the parasite *Diadegma armillata* Grav. is still in the early pupal stage, protects and actually favorably alters the balance between the numbers of parasites and pests.

In the southwestern region until 1960, the premature dropping of plums from trees over a large area was a regular occurrence as a result of damage by *Parthenolecanium corni*. This has not been observed for the last 15 years. The explanation is the proper control of the pest. The parasite *Blastothrix confusa* and other related species were used to parasitize the larvae which had hibernated through the winter, and 30 percent less chemical treatment was used during the pupal formation period. With even higher infestations, no chemical treatments were used since there were a sufficient number of parasites in the subsequent season to completely overcome all female pests.

The use of microbial pesticides, including entobacterine, in combination with the decreased use of toxic chemicals, insures not only high effectiveness in the control of a number of harmful pests but also preserves the basic stock of entomophagous species.

Reducing the use of insecticides in a fruit and vegetable operation will lead to more substitutions of microbiological substances, an abundance of entomophagous species and a cessation of unnecessary prophylactic treatments or use of insecticides which are not dangerous to entomophagous species. Moreover, a determination should be made in every zone where there are numbers of natural entomophagous species that are preying on the basic pest species. This survey should be made for the purpose of scientifically establishing the use of nonchemical alternative pest suppression measures. The role of injurious and parasitic insects, assisted in a number of cases by readily available measures, may increase to the degree where the use of chemical treatment would be unnecessary or sharply reduced.

Such methods could include use of nectar-bearing crops and several other measures. It has been found that the Syrphidae, Tachinidae and other entomophagous species are attracted to cabbage fields planted with nectar-bearing plants of the families of Cruciferae and Umbelliferae. White mustard (*Sinapis alba*) and coriander (*Coriandrum sativum*), when planted in narrow (40 cm) rows among vegetable peas, have caused an increase in the aphid parasites that attack pea fleas. This also has produced an increase in the number of other predators (Syrphidae, Coccinellidae and others) which are 3-5 times more effective in suppressing pest numbers than chemical treatments. These measures can be carried out without the need for insecticides for protecting the peas from fleas.

The planting of nectar-bearing plants in rows on truck farms, including coriander, caraway (*Carum carvi*) and fennel (*Foeniculum vulgare*), insures a constant and successive flowering over a period of 5 months. Calculations have shown that under such conditions entomophagous species have reduced numbers of pests such as *L. pomonella* and *Lithocolletis* by 10 to 20 percent. Numbers of *L. corylifoliella* and *L. pyrifoliella* have been reduced as much as 90 percent at distances of as much as 50 meters from both sides of the row of nectar-bearing plants.

The planting of garden-protecting rows of certain plant species also helps to support a large number of oligo-polyphagous parasite and predators. For example the mahaleb cherry attracts a concentration of

Ageniaspis fuscicollis Dalm., *Diadegma armillata* Grav., *Yponomeuta malinellus* and *Y. padella* and other parasites. Furthermore, the hawthorn (*Crataegus* sp.) attracts a concentration of *Prionomitus mitratus* Dalm., *Psylla pyri* and other parasites.

The introduction of entomophagous species has great promise in the U.S.S.R. for control of pests originating in foreign countries. An example is the Colorado potato beetle (*Leptinotarsa decemlineata*), for which effective natural enemies exist in the United States.

Considering the wide expanse of the Soviet territory and its different climatic zones, there are further prospects for the dispersion of entomophagous species within a field, as, for instance, *Trichogramma* sp., aphidophagous species and the parasite *Diaspidiotus perniciosus*.

The encouragement of dispersion within the same field by entomophagous species, both of new and subspecies, is a new feature in the control of insect pests harmful to vegetable crops which live beneath the soil surface.

A method of seasonal colonization of insect natural enemies on vegetable crops which grow above and below the ground has been used or experimented with and involves *Trichogramma evanescens* Westw., *Chrysopa carnea* Steph. and a number of species of Cecidomyiidae, Syrphidae, Coccinellidae, Aphididae and several others.

Trichogramma evanescens has been successfully used on cabbage to control *Barathra brassicae* in the Ukraine, the Russian Soviet Federated Socialist Republic (RSFSR), Modavia and Belorussia. Tests have been conducted with this parasite in Kazakhstan and Central Asia. The effectiveness of using *Trichogramma* sp., for example, in Moldavia to control the first generation of *Barathra brassicae* has achieved 50-70 percent reductions in pest numbers and has reduced the second generation by approximately 95 percent. The cost of treating one hectare of cabbage averages from 50 kopecks to 2 rubles, but the additional yield produced has amounted to 2000 kg or more per hectare.

In integrated systems, *Trichogramma cacoeciae pallida* and *T. embryophagum* have been used to control *Laspeyresia pomonella* in areas where there is only one generation of the pest and various Tortricidae.

In the U.S.S.R., experience has accumulated in controlling predators on vegetable and field crops. Problems concerning mechanization and automatization of the rearing of a parasite whose lifespan can be protracted (over 24 days) have been solved. Also, questions concerning the mechanization of the rearing and release of *Trichogramma* sp. have been solved.

The research has shown that *Chrysopa carnea* may now be used both for soil insects and those affecting production of tomatoes, eggplant, potatoes and peppers. This includes control of aphids, thrips and the Colorado potato beetle. Thus, to control the eggs and the young larvae of these pests, the first generation of parasites must have a superiority in numbers of a 1:1 or 1:5 ratio in order to destroy 86-90 percent of the harmful insects. The larvae of the second and third generations of *Chrysopa* will, within a period of 5-10 days, exterminate 87-100 percent of the Colorado beetles, even though the pests may outnumber them by 50 to 1. In vegetable fields, the *Chrysopa* larvae of the second generation destroyed the aphids at a predator-to-prey ratio of from 1:1 to 1:25.

Chrysopa is certainly a long-range predator, which can be used with excellent results in a seasonal colonization method. However, before they can be put to practical use, a number of important problems must be solved in relation to an automated breeding process and best means of utilization. The problem of the encapsulation of an artificial diet for the larvae has yet to be fully solved.

Aleochara bilineata Gyll. is a widely distributed parasite, as are the predators of *Hylemya brassicae* Bouché, *H. antiqua* Mg. and a number of species of Diptera. A methodology which was developed to breed *Aleochara* has made it possible in recent years to test them against the *Hylemya* sp. Putting 20-30 thousand beetles on a hectare of cabbage two to three times a year at the correct times has made it possible to protect the crop completely.

The work on *Aleochara* also must solve the problem of mechanizing and automating mass breeding. There also must be mass experiments on the use of entomophagous species in various areas of the country.

A big breakthrough in recent years has been the development of a biological method to control *Tetranychus telarius* L. beneath the soil surface with the help of *Phytoseiulus persimilis* H.A. At the present time the predator is used in glass houses in many Soviet republics. An evaluation from a production standpoint of its effectiveness in Moldavia has shown that the predator is particularly effective when put out on crops when the first signs of a harmful infestation appears. The use of *Phytoseiulus* makes it possible to dispense with 10-12 insecticide treatments and has increased the cucumber harvest from 1 to 5 kg per square meter. The net revenue from 1 square meter of a glass house using predators was increased 2.64-4.90 rubles.

A specific goal for entomologists is the development of a biological method of controlling underground aphids. Tests with Syrphidae to control *Aphis gossypii* on cucumbers have been conducted. The use of eggs and larvae of *Sphaerophoria* Lepeletier & Serville *Syrphus corollae* F. in a predator-prey ratio of 1:5 to 1:50 made it possible in just 5-9 days to destroy 82-99 percent of the research pests. Use of the third and fourth instar larvae, however, has not proven successful.

The effectiveness of *Chrysopa formosa* Br., *C. septempunctata* Wesm., *C. perla* L., and *C. carnea* Steph. also has been verified. *Chrysopa* were tested during the second larval instar in a predator-prey ratio from 1:10 to 1:100, and the use of the *C. perla* in a predator-prey ratio from 1:10 to 1:50 made it possible in a period of 6-12 days to completely control the aphids. *C. formosa* and *C. septempunctata* in a ratio of 1:10 to 1:25 produced 75-95 percent control of the aphids in 2 weeks. *C. carnea* showed less effectiveness on cucumbers, and even at a 1:10 ratio, only 54 percent of the aphids were destroyed. From the start of the control test, the number of aphids increased by 6-7 times.

The larvae of all the growth stages of *Coccinella septempunctata* L., *Adonia variegata* Gz. and *Semiadalia undecimnotata* Schn. were tested in a predator-prey ratio of 1:5 to 1:100. The larvae of *C. septempunctata* in a 1:30 ratio produced pest suppression of 82 percent in a 5-day period and 97 percent in a 10-day period, and at a ratio of 1:100, they produced an 87.7 to 97.3 percent suppression. The use of the larvae in the third instar produced effective control after 5 days destroying 92 percent of the aphids. However, these larvae quickly pupated, and the number of aphids then increased. This was the reason for the poor results produced by the use of fourth instar larvae. The larvae of the two other species of Coccinellidae were less effective.

Experiments in glasshouses with the gall midge predator *(Aphidoletes aphidimyza* Rond.) have shown that if 95 gall midges or a same number of midge cocoons are placed in 1 square meter of a glasshouse, the *aphidimyza* larvae will attack the breeding ground of the melon (or cotton) aphid *(Aphis gossypii)* within 18 to 20 days. Experiments in a production operation affirm the effectiveness and long-term value of this predator.

In recent years, *Diaeretiella rapae* Curt. has been tested for control of *Myzodes persicae* Sulz. The parasite was effective against this aphid on eggplant even when faced with large numbers of the pest. Moreover, the duration of pest suppression may be extended by increasing the respective parasite host.

One of the most injurious soil pests of tomatoes and cucumbers is *Trialeurodes vaporariorum* W. The best long-term means of controlling this pest has been the entomopathological fungus, *Aschersonia aleurodis*. This presently is being experimented with in several areas of the U.S.S.R.

As was shown in this report, there are a great number of biological control weapons in our pest control arsenal. Progress achieved in the last decade, makes it reasonable to expect an even further expansion of biological methods in complex control programs directed against harmful organisms.

Development in this important direction will lead to a full and more complete study of the faunal relationships of the arthropods and their interrelationship with the other aspects of the agroecosystem. A leading role is being assigned to further developing production of entomophagous species on an industrial basis, to safeguarding and separating classification of natural enemies for the protection of plants and to the introduction of major quantities of microbial pesticides for pest control. The growth in the extent of biological methods can be seen from the increasingly large area involved: in 1963, 230,000 hectares; in 1974, 9 million hectares and in 1980, a projected 30 to 35 million hectares, of which 15 million hectares will use entomophagous species, 12 million hectares will be treated with entobacteria and the remaining 8 million will be treated with other microbiological materials.

The social and economic advantages look promising in terms of reducing crop damage, perfecting agrotechnical methods of crop cultivation, a correct system of seed management and introduction of pest-resistant strains. The development of these procedures, as well as the biological ones, should be a feature of integrated control methods, which are based on the detailed analysis of ecological conditions in which nonchemical control of harmful organisms will gradually and increasingly be adopted.

PROBLEMS IN REGISTERING THE USE OF MICROBIAL PESTICIDES

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The U.S. Environmental Protection Agency is responsible for the registration of all pesticides to be used in the United States. They must be used in a manner consistent with the label. Before a pesticide can be registered, evidence must exist that it is effective and acceptably safe for both man and the environment if used as directed on the label.

Most of the pesticides registered are well-defined chemically. Often the active ingredient is a single well-described chemical, and the inert ingredients are either clearly described or common substances, such as petroleum distillates or a talc. In such cases there are definite requirements for necessary evidence. There must be a clear and definite description of the formulation and the exact quantity of each active ingredient, and the nature of each inert ingredient must be made known to the Environmental Protection Agency. Information is required as to what happens to each active ingredient after it is applied. (Is it metabolized and, if so, to what? Does it persist for long periods? Does it move in water? Does it concentrate in the food chain?) The results of field experiments must be furnished to show the degree of control obtained at various dosages. The toxicity of the product to man and to a variety of other non-target organisms which may be exposed to it must be determined. Other considerations are whether it leaves a residue on the crop at harvest or whether it contaminates succeeding crops, drinking water, irrigation water and so on.

Well-recognized test protocols exist for providing such evidence for chemical pesticides. For microbial pesticides, guidelines are less clear. It is difficult to measure the toxicity of a virus or some other microorganism. Ordinarily, the EPA is less concerned with toxicity, particularly with viruses, than it is with infectivity. Generally, viruses are pathogenic only to cold-blooded animals. For instance, a nuclear polyhedral virus has been found that is pathogenic to shrimp; it is, however, distinct from those used in insect control. Some fungi normally not found on man nevertheless have infected man under unusual circumstances and have been very troublesome, hence the concern with possible infectivity of candidate fungal pesticides. Moreover, it is possible that some microbial pesticides could produce toxins affecting man or beneficial organisms.

Another concern is the possibility of occurrence of sensitizing proteins in the cultures. Certain of these microorganisms can be produced only in living tissues, and they cannot be completely separated from the host materials upon which they were grown. The inevitable impurities resulting could produce allergies in sensitive humans. Adequate test procedures for determination of skin sensitization or ocular effects are needed in addition to tests for the toxicity of the impurities in microbial pesticides.

The EPA is sponsoring research on bacteria, viruses and fungi, especially to study safety considerations and to develop test protocols. Meanwhile interim guidelines have been developed for three organizations wishing to register microbial pathogens as pesticides. Experimental use permits have been issued for several fungi as herbicides, such as that for use in the control of northern joint vetch, *Aeschynomene virginica*, in rice fields; for the protozoan, *Nosema*, for control of grasshoppers (*Acrididae* sp.) on rangeland; and for a nuclear polyhedrosis virus for control of the gypsy moth (*Porthetria dispar*) and for the tussock moth (*Lymantriidae* sp.). Such experimental permits allow scientists to gather evidence of the effectiveness of the pathogens as formulated for application. If these microbials prove to be effective and if no evidence of hazard is seen, then they will be registered upon demonstration of host specificity and lack of infectivity for mammals.

Problems in registering microbial pathogens as pesticides are largely associated with lack of knowledge of the chemical and toxicological nature of the effective ingredient. Until better knowledge of the mode of action of such biologicals is obtained, possible unexpected effects will continue to be a concern. Increased concentrations of pathogens naturally occurring in the same evironment are the current problem rather than new introductions, and care must be taken to observe their properties during culture, formulation and application.